PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

CORPS OF ROYAL ENGINEERS.

R. E.

VOL. IX.

LONDON.
JOHN WEALE, 59, HIGH HOLBORN.

M.DCCC.XLVII.

PRINTED BY W. HUGHES,
KING'S HEAD COURT, GOUGH SQUARE.

CONTENTS.

LIST OF PLATES.

PREFACE.

In consequence of the appointment of Captain Sir William Denison to the Lieutenant-Governorship of Van Dieman's Land, and of my having succeeded him as Director of Public Works in the Royal Dockyard at Portsmouth, I was requested by him, and the Officers assembled at a meeting in September last, to edit this the Ninth Volume of the Professional Papers of the Corps. This task I readily undertook, more especially as the greater part of the Papers in this volume had already been collected; and I was glad, by so doing, to have an opportunity of obliging an old and valued friend, and also to meet the wishes of so many of my brother Officers.

At the same meeting, Captain J. Williams, R. E., was requested to superintend the publication of these volumes for the future, and to suggest any alterations in the character of the work, or mode of publication, which he might consider desirable, and to submit them at the Annual Meeting of Officers, to be held on the 1st February this year, for their approval.

At the meeting which was held on that day it was arranged that Colonel Lewis, R. E., should be associated with Captain J. Williams as joint Editor, and that they should submit a plan of publication at an adjourned meeting to be held on the 23rd February; and in consequence, at the meeting on that day, the following arrangements, proposed by those Officers, were approved and adopted, viz.:

1st. That *Corps* Papers, comprising subjects of little interest to the Public, or to Civil Engineers and Architects, to include—

Military Memoirs,
Military Reports,
Construction of Works and Buildings,
Unexecuted Projects,
Documents from Public Archives,
Notices of New Publications,
General Matter interesting to the Military Engineer,—

shall be published by the Corps under the direction of the Editors, in octavo, corresponding in size and style with the 'Aide-Mémoire,' and for circulation in the Corps, and amongst Subscribers *only*, to whom the Papers will be sent as heretofore: the cost not to exceed 10*s*. per annum for each Subscriber, who will have a small pamphlet of about six or seven sheets, or 96 or 112 pages, every six months;—these may be bound up in volumes to suit Subscribers.

2nd. That *Professional* Volumes, to embrace matters of general interest to the Public, the Civil Engineer and Architect, as well as to the Military Engineer in particular, to correspond with the existing 'Professional Papers' in size, type, and engravings, shall also be published: the purchase of this work to be optional when the volumes are out, and not by subscription: to be published by such persons as may be deemed most eligible by the Committee, reserving the claim, that any Officer of Engineers shall or may obtain a copy at the trade price; and that the Publisher shall also supply the Corps Libraries at the same rate for the number of copies required for them.

The *Professional* Volumes to come out when sufficient matter is collected, which the Editors anticipate will be at the rate of two volumes in three years.

It was also agreed at the same meeting, that Mr. Weale, who has published the 'Professional Papers' in the superior manner in which we now have them, should be offered the publication of the 'Professional Volumes' on the above-mentioned condition: this offer Mr. Weale has accepted.

It will be seen by the adoption of the second Resolution, that the 'Professional' volumes to be published will in fact be a continuation of the present work, and those Officers who wish to continue to subscribe to it have only to write to that effect to Mr. Weale, and authorize their Agents to pay him for each volume as it appears. In the Preface to the first volume, the want of such a work as this is stated to have been generally felt by the Corps, and the number of our Officers (250) who have constantly subscribed for it have fully borne out that statement. Amongst the Officers of the East India Company's Engineers we have had 112 Subscribers, besides which, the East India Company, as a Government, have regularly subscribed for fifty copies to be sent to their principal stations; and this notwithstanding their own Engineers in the Madras Presidency publish a quarto volume of 'Professional Papers;'* to which, it must be presumed, a majority of the East India Company's Officers also

* Edited by Captain J. T. Smith, F.R.S., &c. The second volume has reached me, and contains many interesting and valuable Papers.

subscribe. Amongst the Officers of the Royal Artillery we have forty-eight Subscribers, and many from other Corps. Copies are also sent by Mr. WEALE to almost every Military Library in the capitals of Europe and America.

These publications have proceeded regularly from the first,—the volumes increasing in interest and value as they have succeeded each other. The work has now reached a high degree of reputation; and it is deeply to be regretted that the energetic mind that conceived and brought it to maturity, has not remained amongst us still to foster and protect it.

No doubt, as has been urged, the great size of these volumes renders them too bulky for Officers to carry them about without inconvenience; but considering how necessary it is that information of the character contained in these volumes should be accessible to our Officers, to enable them properly to perform their very various duties, and the anxiety they have felt to procure such information,—it is not only probable, but almost certain, that if this subject had been properly represented to the Government, it would have felt that it was both its interest and its duty to follow the example of the East India Company, and to have subscribed to at least an equal amount for this work. Had such a subscription been given, it would have been ample for the supply of a copy to every principal station both at home and abroad; and thus for a trifling sum the experience of the Corps would be treasured up, and the various information on Military Subjects, on Works and Machinery of every kind, which these volumes contain, would be available and accessible to our Officers, as well in the distant Colonies as at home. It is well known that the want of such information too often leads to the expenditure of large sums of money on works, comparatively speaking, ill-contrived and unsuited for their object; nor was it to be anticipated that such a subscription would have necessarily led to the withdrawal of a large number of Subscribers; the example of the East India Officers proves the contrary, and I have no doubt but that a large number of our own Officers would also still continue to subscribe. I cannot therefore refrain from expressing a hope that the Government will encourage the publications which have now been undertaken, and send them free of charge to the Officers of the Corps wherever they may be quartered.

These volumes have been purchased by almost every Officer of the Corps, not for his personal gratification, but the better to enable him to discharge his various duties; but unless the information they contain is 'garnered up' by the Government at our stations, the fruits of our labour will be lost to those who succeed us.

I feel assured that it will be gratifying to the Corps, and to the Officers who have subscribed to the 'Professional Papers,' to learn that, at the meeting which was held

in September last, the Officers there assembled voted as from themselves only, (they were not authorized to represent the Corps in this matter,) a piece of plate to Sir W. DENISON, on which the following inscription is engraved:

"Presented by his Brother Officers who attended the Meeting of the 23rd September, 1846, to Captain Sir WILLIAM DENISON, Royal Engineers, as a token of grateful remembrance, that to him alone they are indebted for having originated the diffusion of individual experience by means of 'Professional Papers,' which he has continued to conduct for a period of Ten Years, until he was appointed to the Government of Van Dieman's Land."

HENRY JAMES,
Captain, Royal Engineers.

8th March, 1847.

Corrections in Paper III.—'Project of Defence.'

Page 36, line 8.—Read 'directly towards its own front.'
" " 14.—Read 'placed in galleries (x, x).'
" " 30.—Read 'as adopted in Plan III.'
" " 32.—Read 'by ditches, each defended,' &c.
Page 37, line 23.—Read 'section A B C D E, Plan II.'
" 39, " 8.—Read 'parapet wall, 4 feet thick.'
" " 21.—Read '1 casemate gun or 1 howitzer.'
" " 26.—Read '30 men may be accommodated.'

PROFESSIONAL PAPERS.

I.—*Observations on the Value of Fortresses, Intrenched Camps, and Field Fortresses (Places du Moment*[1]*); their Application to the present System of Railroads for the Protection of the Metropolis south of the Thames; including some Notices on the Works at Lyons and Paris. By Colonel* Lewis, *R. E.*

I. PRELIMINARY OBSERVATIONS.

Whilst fortifications have been constructed on a vast scale at Paris, Lyons, and Grenoble, in France; at Coblentz, in Prussia; and Rastadt and Lintz, in Germany,—and various other places in Europe,—the defences of Great Britain and Ireland have not multiplied or been enlarged since the Peace of 1815. Is it that we are so wise, and other nations so prodigal of their wealth, and that they have neither considered the utility and importance of such expenditure? And are those prejudices which existed sixty years ago, when the projects of the Duke of Richmond, as Master-General, were rejected as not applicable to those times, still to influence us, when standing armies and fortresses are no longer constitutional bugbears? The pamphlets, however, of le Prince de Joinville and Viscount Ranelagh have awakened attention, without creating alarm; the country looking to three-deckers and war steamers, and arming the maritime fortresses, as a security against every danger.

With immense wealth, with the probable expenditure of seven hundred millions in the construction of railroads, inexhaustible resources, and a superabundant population, we are comparatively the weakest military nation for

[1] See Bousmard, livre v. chap. ix.

defensive purposes in the world; for our coasts are open, the roads between them and the metropolis excellent, and the intermediate country without a military post or feature or natural obstacle to arrest an enemy.

In considering the value of fortresses, many recollections tend to foster our repugnance to them,—such as the fate of Magdeburg, after the battle of Jena; the capture of those in the north of France, after the battle of Waterloo; and of those in Holland, in 1795, by the French armies. And it may be observed, that it is useless to expend immense sums on fortresses if they fall into the hands of an enemy in a few days, and if their strength is only accidental. But the science of fortification out of England is not diminished in estimation, although, by the decay and exhaustion of empires, Valenciennes fell in 1815, when it resisted in 1795 a bombardment without bomb-proofs, and a regular attack of many weeks. St. Sebastian resisted as many weeks in 1813 as it did days a century before against the Duke of Berwick. When fortified places are estimated in importance for the security of a frontier or a capital, it must be with reference to the military institutions and spirit of nations.

On the continent of Europe, the art of fortification was never in greater repute, since the time of Vauban, than at this moment, that Engineer not being responsible for its abuse or misapplication; and Bousmard (livre v. on the Defence of Empires by Fortification) observes—

"Il est question maintenant, de considérer la défense de l'ensemble du pays, du corps de l'état, de tout enfin, pour l'intérêt et le salut du quel la fortification de ses diverses parties a été ou du être ordonnée. C'est ici l'objet de la fortification, vu en grand, et son utilité envisagée relativement à la stabilité des empires, à la securité des gouvernemens, et à la protection qu'ils doivent aux peuples contre la guerre et ses ravages; et si les livres qui précédent, ou peut-être considérés, les uns comme la fortification de l'officier en général, les autres comme celle de l'ingénieur ou du commandant de place en particulier; celui-ci, s'il remplissoit bien son titre, pourroit être à bon droit, regardé comme la fortification du général d'armée, du ministre d'état, du prince, roi ou chef de l'état, de quelque nom on veuille l'appeler. . . . .

"Par défendre les états par la fortification, je n'entends point uniquement les hérisser sur chaque avenue ou partie accessible des frontières, du places fortes qui vous forcent à faire un siége à chaque pas que vous y ferez. J'entends une combinaison des moyens de l'art avec les moyens défensifs de la nature, telle que ceux-ci deviennent insurmontables, tant que ceux-la n'auront

point succombé. J'entends par les moyens d'art, non seulement les places fortes, mais encore les camps retranchés et positions fortifiées, les camps retranchés sous les places, ceux alongés en lignes pour couvrir un pays, les abattis, les inondations, canaux, routes et communications militaires, enfin les postes retranchés; en un mot, tout produit d'art, qui concourant avec les obstacles naturels, compose avec eux un ensemble capable de donner aux défenseurs d'un état, toutes sortes d'avantages sur ceux qui l'attaquent."

Intrenched Camps are more in disuse, and even less appreciated, than fortresses; but there is a great distinction in the nature of this description of fortification. Temporary intrenched camps, for the mere security of an army for a short period, are seldom constructed in modern times, and, when executed formerly, they were generally in connection with existing fortresses, and of a somewhat substantial character. Permanent intrenched camps have been recently constructed at Ulm and at Lintz, in Germany, as explained by Lieut.-Colonel Blanchard and Colonel Stavely, in the second volume of the Professional Papers; and it is proposed to give here a sketch, taken from a French work[2] recently published, of those lately constructed at Lyons and Paris (see Plates I. to IV.)

II. FORTIFICATIONS AT LYONS.

(Vide Plate III.)

It appears that the fortifications of Lyons form a vast chain of detached works, supporting each other, in front of the principal lines or enceinte which cover the city on all sides.

It is hardly necessary to state that the city of Lyons is situated at the junction of the rivers Rhone and Saone, with the suburbs of Guillotière and Broteaux on the left bank of the Rhone, and those of St. Irénée and Vaise on the right bank of the Saone. The first of these suburbs, Guillotière and Broteaux, is protected by eight forts and two lunettes, distant about 550 yards from each other. Commencing above the stream, they consist of, or will consist of,

1. A projected Redoubt, opposite the suburb of St. Clair.
2. The Fort of La Tête d'Or.
3. The Lunette des Charpennes.
4. The Fort des Broteaux.

[2] By Le Baron P. Emile Maurice, Capitaine du Génie.

5. The Fort de la Part-Dieu.
6. The Fort de Villeurbanne.
7. The Lunette des Hirondelles.
8. The Fort La Motte.
9. The Fort Colombier.
10. The Fort de la Vitriolerie.

These ten works cover the east of Lyons, and are connected by a curtain with banquettes, and a military road secures the communication from fort to fort.

The north of the city of Lyons, forming the peninsula between the two rivers, is covered, or will be covered, by

1. A projected Lunette, to be called Bel-Air.
2. Fort Montessuy, and its two Lunettes.
3. Fort de Caluire.
4. An enclosure of several fronts, commencing at Porte St. Clair, and terminating on Fort St. Jean, opposite the Bridge of Serin.

On the right bank of the Saone, enclosing the suburbs of St. Irénée and Vaise, are, or will be,

1. Fort de Sainte Foy.
2. A projected Redoubt, near the Aqueduct.
3. Fort St. Irénée.
4. The Lunette du Fossoyeur.
5. The Fort de Loyasse.
6. The Fort Vaise.
7. The Battery de Pierre-Scise.
8. The old line of works, raised and reconstructed, called the Enceinte de Fourvières.
9. A projected work, to be placed on the Plateau de la Duchère.

These extensive works, so placed as to secure the approaches to the city, give shelter to a powerful intrenched camp, which could not be blockaded with a force less than 300,000 men, whilst within there is every facility of support and free movement to the garrison: each, if minutely examined, would afford to the military Engineer an interesting study: those on the left of the Rhone are adapted to low ground, and the others for hilly country.

As detailed plans cannot be given, a minute description will supply as much as possible these wants: some of the works are only projected, and it will require about £280,000 to complete the whole system of defence for Lyons.

East Line of Defence.[3]

Fort de la Vitriolerie is built upon an island, the water surrounding it made to serve as an advanced ditch, 9 ft. 10 in. deep;[4] the fort, a sort of crown-work revetted, of which the bastions have short faces and long flanks, to see the ditches well, and protect the centre bastion, which has the casemates of two stories, with embrasures in the flanks and loopholes to the faces. The curtains are also casemated, but only with one floor: the gorge of the fort contains defensible barracks, bomb-proof, for 800 men. This work has an excellent command over the low ground.

Fort Colombier, distant 766 yards from the former, is constructed in a re-entering angle of this line of defence, and is consequently of minor importance. The fort is a kind of bonnet de prêtre, with the angles very obtuse, flanked by a *bastionet* (see Plate I. figs. 1 to 5): it is revetted by a detached escarp, as explained at A, fig. 3, Plate I., with a chemin de ronde which goes all round the work, in which it will be perceived that there is an essential difference between it and the escarpe detachée of Carnot's system.

The wall which covers the chemin de ronde is 9 ft. 10 in. high, and is attached to the exterior slope of the body of the place by counterforts, which serve as traverses; and being arched, the communication along the chemin de ronde is not interrupted, and at distances between them machicoulis are constructed, to see the foot of the escarp.

The middle of the gorge of Fort Colombier is occupied by a defensible barrack, bomb-proof and loopholed: the gorge is terminated by two half-bastions, (figs. 6 to 9, Plate I.)

Fort de la Motte is an irregular square, placed to command the roads to Antibes and Hamburg. On the road towards Antibes, an old château is enclosed by the terreplein of the bastion, and in the salient angle of the bastion is placed a casemated bastionet, which communicates with the chemin de ronde of the detached escarp. This description of work, introduced into the French system, seems to correspond with the caponière of the Prussian or German, as explained in fig. 3, Plate I.

Fort de la Motte is surrounded by a wet ditch and covered-way, with flanks on two fronts, and an advanced lunette, connected by a caponière. In the

[3] See Plan of Lyons.

[4] These dimensions are the equivalents of those given in metres,—hence the odd inches.

centre of the fort there is a square redoubt in masonry, and in the gorge a casemated barrack.

Lunette des Hirondelles is about half-way between the former fort and that of Villeurbanne, and 55 yards in extent, measuring along the detached escarp which surrounds the parapet of the lunette, and flanked by bastionets: a defensive barrack serves for the redoubt within.

Fort de Villeurbanne is a bastioned work with five fronts, those to the south being 273 yards, and those to the north or rear 219 yards, and is surrounded by a wet ditch. The bastions are deep, and are intrenched *en cavalier* or *en tenaillons*. The counterscarps are revetted, and, when possible, with a reverse fire. The interior redoubt is quadrilateral, revetted by an escarp in part detached, with loopholes and machicoulis. The land side of the quadrilateral has a bastionet to flank it (see figs. 2 to 5, Plate I.), and the two faces on the right and left of the gorge half-bastionets. The defensive barrack in the gorge is upon a peculiar construction, as shown in figures 6 to 9, and the gate and draw-bridge is protected by a barbican and machicoulis. The terreplein of the fort forms the ditch of the redoubt.

Fort de la Part-Dieu, or rather lunette, is not revetted, but it is flanked by small half-bastionets at the salients: it has, likewise, an advanced wet ditch.

Fort des Broteaux has three fronts of 284 yards, with a gorge of 437 yards: the latter is flanked by a redan, and contains the barracks and magazine. The interior redoubt seems to correspond with that of Fort Villeurbanne.

Lunette des Charpennes, revetted and casemated throughout, loopholed, and dry ditch, with a glacis and advanced wet ditch. This work sees the reverse of the Forts Broteaux and Tête d'Or, which constitutes the peculiar value of this lunette.

Fort de la Tête d'Or is precisely upon the same construction as Fort du Colombier.

Redoute du Haut Rhone, a projected work, to take in reverse the approaches to Fort de Montessuy, on the other side of the Rhone.

Line of Defence on the Peninsula between the Rhone and Saone.

Fort Montessuy is a quadrilateral bastioned work, of which the south front is 208 yards, the east 240 yards, the north 208 yards, and the west 197 yards, on the exterior sides. The escarps are in part detached (see fig. 3, Plate I.): the

interior retrenchment is a large cavalier, with an extensive command outside. The casemated barracks are placed in the south front.

Fort de Caluire.—The ground slopes gently to this fort from the former, which commands and flanks it at a distance of about 656 yards: the trace is also quadrilateral, with fronts of 197 yards. The escarps are detached, with loopholes and machicoulis. The intrenchments are formed of a cavalier and redoubt, as explained in Plate II. To see down the slopes towards the River Saone an advanced covered-way is constructed, which, with the occupation of the château on the Ile Barbe, commands the approaches in reverse.

Fort St. Jean is placed at the extremity of the enceinte which encloses the peninsula: it forms an amphitheatre of casemated batteries, which plunge into the Saone and slopes of Vaise, and are constructed upon the principle proposed by General Haxo, which avoids many of the inconveniences peculiar to casemated batteries, as explained in Plate II.

Enceinte continue de la Croix-Rousse is the old enclosure, with very few alterations, which commences at the gate of St. Clair, and closes at the suburb of Serin: the orillon bastions have been repaired, the curtains casemated, and before bastion No. 7 there is a specimen of the perpendicular fortification.

Line of Defence on the Right Bank of the Saone.

Fort de Sainte Foy.—There were some difficulties in fixing upon the emplacement of this work: this arose from the position of the village of St. Foy in front, and the distance from the Fort St. Irénée in the rear. The fort is quadrilateral, of which two sides are bastioned, that to the south being 361 yards, that to the north 273 yards, and the others 219 yards. The escarp and counterscarps are revetted, and the bastions have casemated batteries à l'Haxo constructed in the parapets.

Fort de Sainte Irénée, immediately in front of the Enceinte de Fourvières, is a large flat lunette, with an escarp in part detached, with chemin de ronde, and flanked by small square bastions. The counterscarp is revetted, with reverse fire. The terreplein of the lunette is cut into two by a cavalier, and a defensive barrack occupies the gorge.

Fort Loyasse is placed upon peculiar ground, and is revetted throughout, without glacis or covered-way: the ditches are narrow and deep. The flanks of the bastions are casemated, and the bastions of the west front are casemated

à l'Haxo. The barracks are placed in the gorge facing the city. The west front is 328 yards, that to the south 273 yards, and that to the north 164 yards. The bastions of the west front have cavaliers.

Fort de Vaise, 328 yards to the north of Fort Loyasse, occupies the extremity of the plateau which commands the village of Vaise: its shape is regulated by the ground, and the faces are flanked by the reverse of the ditch (see fig. 8, Plate II.), which communicates with the interior of the fort. The interior comprises three distinct squares, en cavalier.

Enceinte continue.—This line, comprising five fronts, connects the bridge of Ainay with the Fort Loyasse. The bastions are all closed at the gorge, with bomb-proof guard-rooms. The works executed are based upon the old walls of the fifteenth century.

M. Emile Maurice, in conclusion, observes, that the fortifications at Lyons offer to the military Engineer various interesting considerations for study, where a part are peculiarly adapted to low ground, and others to hilly country, and no exclusive system followed, but the details are especially suited to the locality. He also notices that the works at Lyons were not constructed under the same advantages as those executed at Paris, where a well-digested system of defence has been completed; those at Lyons, built under the direction of General Rohault de Fleury, being planned as money was granted for the defences.

III. FORTIFICATIONS FOR THE DEFENCE OF PARIS.[5]

(See Plate IV.)

Paris is situated à cheval on the Seine, near the junction of the Marne, the latter river covering the city on the east, and a bend of the former the western side. Extensive works connect these rivers by a chain of detached forts supported by an enceinte continue immediately around Paris; and as the bastion system is adopted throughout, the extracts of the details will not occupy much space.

The Exterior Line of Defence of detached works, commencing at St. Denis on the north at a re-entering angle, on the right bank of the Seine at the junction of that river and the canal of St. Denis, and the Northern Railway and high road to Calais, and extending to the Marne at Nogent, a distance of about 8 miles, first comprises nine forts, namely,

[5] By Le Baron P. Emile Maurice, Capitaine du Génie.

1. Couronne de la Brèche,
2. Double Couronne du Nord, } surrounding the village of St. Denis.
3. Fort d'Est,
4. Fort d'Aubervilliers.
5. Fort de Romainville.
6. Fort de Noisè.
7. Fort de Rosny.
8. Fort de Nogent.
9. Château and Fort de Vincennes, in rear of and supporting the two former.

This line of defence closes the approach from Germany.

The three works surrounding St. Denis have their fronts from 328 to 547 yards, and the intermediate ground can be inundated.

Fort d'Aubervilliers is a parallelogram with five bastions, apparently without any outworks.

Fort de Romainville, to the south of the Canal de l'Ourcq, on the road to Prussia, extending over the meadows of St. Gervais and plain of Vertus, the theatre of several actions in 1814, is a four-sided bastioned fort, of which the curtains are casemated. The fort is divided into two parts by a cavalier, and called the upper and lower forts. A horn-work is thrown out on the north, to protect ground undermined by plaster of Paris quarries.

Fort de Noisè, about 1640 yards to the right of the former, is a square bastioned fort, with a horn-work in advance of the north-east front.

Fort de Rosny, still more to the right, and to the south about 1968 yards, and covering the villages of Montreuil and Bagnolet, is similar to Fort Noisè, except having a double front in advance to the east.

Fort de Nogent, 2843 yards to the south, and closing on the Marne, is also similar to the preceding works, and completes the exterior line of defence on the north and east of Paris.

Château and Fort de Vincennes consists of a bastioned work surrounding the old castle, supporting the two works Noisè and Rosny in advance.

The second Exterior Line of Defence, covering Paris on the south, and extending from the River Marne to the Seine, about 7 miles, commencing at Charenton, and extending to the forest of Meudon, is protected by six forts, viz.

1. Fort de Charenton.

2. Fort d'Ivrey.
3. Fort de Bicêtre.
4. Fort Mont-rouge.
5. Fort Vauvres.
6. Fort d'Issy.

Of these forts, which complete the defence of the south of Paris, four are pentagon and two are quadrilateral: their escarps are revetted with good relief, and built of substantial materials: the curtains are casemated, and the barracks are bomb-proof; the flanks of the bastions deep, and well adapted to defend the ditch and counterscarp. These six powerful works completely command the approaches to the city on that side, and support each other.

The third Line of Exterior Defence occupies an extent of about 8 miles, and is protected by the citadel of Mont Valerian, which serves as a tête-du-pont to the bend of the Seine which covers Paris to the east, supported on one side by Fort d'Issy, and the works of St. Denis on the other. The fortress of Mont Valerian is a powerful pentagonal bastioned work, having its highest point 426 feet above the level of the canal of La Villette. The base or rear front on the river is 459 yards, and the four other fronts average 328 yards: each bastion has a cavalier, with a command of 96 feet, and there is bomb-proof cover for stores and 4500 men: this work may be considered the most formidable of the detached forts around Paris, which embraces an extent of 22½ miles as the mean circumference of the line on which the works are disposed.

The Enceinte Continue

is one vast range of fronts of fortification, containing ninety-four bastions, the exterior sides averaging 328 yards, forming an enceinte of about 30,840 yards, the most extensive perhaps ever constructed, at a cost of £32,000 per front. The escarps average 32 feet 9¾ inches in height, and the breadth of the ditch 82 feet, with a rampart, counterscarp, and glacis. The fronts, being generally constructed upon a right line, give a support to each other, adding considerably to their strength. The distance from the boulevards of Paris to the ramparts of the enceinte averages 1093 yards, and the same distance from thence to the detached forts; therefore the city may be considered out of range of bombardment, so long as the detached works remain untaken.

In respect to the defence of Paris, M. Emile de Maurice observes, "Il est naturel de se demander si les quatre-vingt-quatorze fronts bastionnés de l'enceinte continue et les quinze forts détaches qui vont transformer Paris en une place de guerre de premier rang, constituent une entreprise dont l'immensité et la dépence soient compensées par l'importance des resultats qu'on pourrait en attendre." But M. Maurice does not solve this question himself.

Marshal Marmont considers the fortification of Paris "as an event the most useful and important for the defence of France, but that it was unnecessary to fortify the city with the enceinte continue." [6]

IV. OBSERVATIONS UPON THE VALUE OF FORTRESSES.

Marshal Marmont defines fortresses as those of dépôt, and for strategetical purposes, to which may be added maritime fortresses. Guibert, who held the métier of an engineer very cheap, induced the Emperor of Germany, by his writings, to dismantle all the fortresses in Austrian Flanders; but time has effected those *revolutions* in most Governments, those changes in the organization of armies, in tactical operations, and the use of immense trains of artillery, and the conversion of every town into a fortified place, of which, in his 'Essai Générale de Tactique,' he exhibited the folly. Fortification as a science and art is now applied in the manner contemplated by that talented author, that fortresses should be large and few in number, and their destiny regulated by battles: that they should be considered accessories and not principals in war; for if they are small,[7] they are neither rallying points nor points d'appui, nor serve as dépôts to receive succours; they are easily taken or masked, and left behind without inconvenience, for it is rare to see a small garrison turning the defensive into the offensive; whereas large fortresses can receive the débris of a beaten army, become the entrepôt of provisions and stores, and capable of containing a sufficient force to resume the offensive when opportunities occur.

[6] I am disposed to differ in opinion upon this point, now that the vast expense has been incurred. Before the construction of the bastioned enceinte, it might have been a question of economy or propriety of expending so large a sum of money; but now that the work is finished, the materials durable, and the climate favourable to the preservation of masonry, I conceive the enceinte to be of immense importance in support of the advanced works and security of Paris.

[7] Such as we in the British Service execute, as constructed at Kingston in Upper Canada, Halifax, Nova Scotia, St. Pierre at the Mauritius, the Circular Redoubt at Harwich, Fort Wellington at Ostend, and Fort Tignè at Malta. Volume vii. of the Corps Papers gives plans and sections of the three last, as well as the three and four-gun towers, which may be considered small forts.

Lloyd in his 'German War' observes, that "most men think a fortress[8] or camp is well placed if they cannot be approached without great difficulty, which is true only in case they have in themselves all the resources necessary for their defence; but as this seldom or ever happens, the perfection of the one and the other would be, to find a situation that presents to the enemy all the difficulties possible, which at the same time may be easily succoured, if necessary."

The functions of fortresses are likewise, that they cover a country, and thus subject an enemy to the necessity of attacking them before he can penetrate further. These things being considered with others already adverted to, the position of a fortress will be found advantageous by being placed at the junction of two rivers, because in such situations the enemy will be obliged to divide his army into three distinct bodies before he can be able to invest it, one of which may be repulsed and discomfited before the others can succour them. Thus two sides of the fortress remain open until the blockade is completed, which cannot be done in a single day; neither can the necessary communications between the divisions of the enemy be kept up without the use of *three* bridges, which will be exposed to the hazards of the sudden storms and inundations which happen in the campaign season.

Recurring to the principle of defining fortresses for the defence, as

1. Maritime places,
2. For the security of dépôts,
3. As strategetical points,

it is proposed to consider the method by which each should be fortified, without reference to any especial system.

1. *Maritime Fortresses.*—It is conceived that a simple enceinte, comprising only a rampart, ditch, and covert-way, is ample protection to a maritime place, with a chain of detached forts in advance, so as to protect the docks and stores from bombardment: the number of forts necessary must depend upon localities; those in front of the enclosures at Lyons and Paris are good specimens of detached works. The enceinte enclosing the naval arsenal may be constructed upon any system best adapted to the ground without outworks, but unassailable by escalade;[9] and it is not deemed necessary to have a large

[8] The fortress of Pampeluna is a notable example of a place falling by blockade, in consequence of the impracticability of relieving it, situated in the bosom of a chain of mountains, only accessible through difficult passes. See Jones's 'Sieges,' third edition.

[9] That is, the escarps 30 feet, if the ditch is dry.

quantity of bomb-proof cover, or more than is sufficient to secure the combustible stores.

2. *Fortresses for the security of dépôts* of arms, ammunition, and for the manufacture of warlike stores, should be constructed with the due care and skill that money can provide for, with adequate bomb-proof cover, in proportion to the size of the fortress, as explained in the article 'Defence of Fortresses' in the 'Aide-Mémoire to the Military Sciences:' the fronts of fortification (whatever system may be adopted) to be countermined, if the ground will permit.

3. *Strategetical Fortresses*, for the support of an army in the field.—The value must depend principally upon the locality, which it is not possible to explain without reference to particular territories, except that already adverted to at the confluence of rivers; but Lyons, Strasburg, Mayence, and Luxembourg are strategetical points of importance. This description of fortress can only be applied to large possessions; as regards the British empire—such as the Canadas, British India, England, and Ireland.

There is no probability that such an expenditure as alluded to above, or as that incurred at Coblentz, Magdeburg, and Ulm, will ever occur in our Service; but it is conceived that some principle might be applied to fortresses of this nature upon a modified scale of expense.

This subject has occupied the attention of the author of these pages many years, and he would propose to limit the construction of strategetical fortresses to a simple enceinte[10] of *rampart*, *ditch*, and *covert-way*, without outworks, upon any system best adapted to the ground, and with not more flank defence or break in the right line than 22 yards exterior face of such flank for two guns, or four if casemated.

This enceinte, to be considered the inner line for such other works in advance, to be constructed according to the value of the fortress in a strategetical point of view; and hence the first expense would be one-third of the cost of ordinary fortified places, and hence will be avoided the necessity of keeping a large garrison for the security of extensive outworks. Eventually, as circumstances dictate and danger threatens them, considerable advanced works, to which the enceinte is the principal support, should be added, according to the probable views of an enemy, or the object of the military chief who may choose

[10] See Plate V.

to make this and other similar fortified places the support and base of offensive or defensive operations. The description of the advanced works will necessarily depend upon localities; and the suggestions of Colonel Hamilton Smith, in the article 'Defensive Elements' of the 'Aide-Mémoire,' offer several available resources to works of this kind; where vegetable nature may be taken advantage of, according to climate, and plantations formed where the fortress is constructed. The drawings in Plate V. will explain generally the scheme here conceived for strategetical fortresses, the dotted lines showing the probable advanced works, and the construction of the enceinte may be a flat bastion front with casemated flanks, and en tenaille with a caponière; or a salient angle with a bastionet (see Plate I.); or a front of fortification with orillons; or straight lines with a reverse fire, and countermines; or, if in low, marshy situations, the systems of Coehorn followed as regards the body of the place: the escarpe detachée (see fig. 3) may be applied; and if rising ground within the enceinte presents favourable opportunities, cavaliers may be formed on the high ground. The trace, however, should have particular reference to the probable construction of the advanced works.

No ingenuity or originality is claimed in this proposition; it is only returning to first principles of defensive works, that of a body of men being able to resist a much larger force, which principle has been gradually lost sight of since the time of Vauban, and several schemes of extensive and costly outworks have been invented to remedy the defects and improve the bastion system.

To counterbalance such defects as may be inherent to a simple enceinte in the description of fortification here suggested for strategetical purposes, are the following advantages:

1. Economy.

2. The facility by which nature and art can be combined, without a considerable outlay, to render the first subservient to art.

3. The avoidance of enfilade; the giving a better command and defence to the capitals of the polygon.

4. The construction of the covert-way may be arbitrary, of any form or breadth to facilitate sorties.[11]

[11] If the ground is favourable, and sloping towards the enceinte, it may be cut as at *Ceuta*, in flèches, with a cover of about 4·6 parapet. In palisading the covert-way, some of the bays, if the palisades are constructed of posts and rails, may be formed as proposed by the late Major

5. The enceinte cannot be surprised.

6. Finally, the fortress is to be considered an accessory, and not a principal, and to depend upon an army in the field.

V. OBSERVATIONS UPON PERMANENT INTRENCHED CAMPS.

Intrenched camps[12] may be considered strategetical fortresses of less strength, and infinitely less expense; but the former are destined for armies with limited resources, whilst the fortresses would necessarily be the entrepôt for strategetical operations.

With reference to intrenched camps, as proposed by Vauban,[13] in conjunction with fortified places, and adopted at Bayonne in 1814, (*vide* Jones's 'Sieges,' and adverted to by Bousmard in the 3rd volume and 7th chapter of the fifth book,) he directs the following to be observed in these cases.

"Qualités nécessaires aux situations des camps retranchés sous les places.

"1°. Que l'air y soit bon, sain, et qu'il y ait auprès de bonnes ceux a boire.

"2°. La situation supérieure ou du moins, égale à tout ce qui l'environne.

"3°. L'espace suffisant pour pouvoir contenir à l'aise toutes les troupes qu'on y voudra mettre et celles même qui pourraient y survenir de renfort.

"4°. Qu'il puisse être avantagè de la difficulté des accès dans une grande partie de son circuit. Ces difficultés pour l'ordinaire consistent en défilés, chemins étroits, fossés, ravines, ruisseaux, rivières, pays serrés et coupés de bois, broussailles, marais, inondations, escarpements, pentes raides et difficiles, et généralement tout ce qui peut faire empêchement, rompre un ordre de bataille, retarder une marche, &c.

"5°. Qu'on en puisse appuyer la droite, ou la gauche, ou la derrière sur la ville qu'on veut protéger, en sorte qu'elle en puisse covrir un des flancs ou quelque autre partie considérable.

"6°. Que l'ennemi ne puisse se mettre entre deux.

"7°. Que les accès des attaques les plus marquées soient réduits, autant que faire se pourra, à un front égal ou plus petit que l'un de ceux du camp.

"8°. Que ce retranchement soit tellement disposé et couvert de parapets,

Lefebre, R. E., so that the upper part of the palisading between the posts may fall back on the crest of the glacis by drawing a bolt, the rails serving as steps up from the banquette.

[12] Intrenched camps for temporary purposes may be said to be in disuse.

[13] *Vide* plan to article 'Camp, Intrenched,' in the 'Aide-Mémoire to the Military Sciences.'

traverses et épaulements a preuve du canon, que les défenses n'en puissent être enfilées, ni les retranchements battus à revers.

"9°. Qu'on n'y souffre point d'ordures, mais que tout y soit propre et toujours net, renouvelant souvent les latrines, et ayant bien soin de faire enterrer les immondices et bêtes mortes loin du camp et fort avant dans terre, et prendre garde que les bouchers ne fassent pas leur tuerie trop près.

"10°. Qu'on puisse tirer des vivres de la place même, ou de quelque endroit ou l'ennemi ne les puisse ôter.

"11°. Bien assurer des marches et communications aux places voisines, afin d'en pouvoir tirer les commodités nécessaires.

"12°. Que le camp soit très-bien fortifié, non pas des retranchements negligées qui couvrent à demi-corps, mais par de bons parapets élevés à trois banquettes, épais de 9, 12, 15 à 18 pieds au sommet, selon qu'ils seront plus ou moins exposés; environnés de bons fossés, fraises et palissades, et surtout bien flanqués, avec des batteries gabionnées, disposées de sorte qu'elles aient toutes leurs vues et découvertes libres et bien tournées sur tous les environs, spécialement sur les principales avenues.

"13°. Que tous les abords soient parfaitement soumis aux vues et découvertes de canon, tout aussi loin que sa portée se pourra étendre."

Independent Permanent Intrenched Camps, an adoption of late, for strategetical purposes, and to cover a line of country, or the approach to the metropolis, occupying a position which an enemy can neither turn nor leave behind, will require most of the qualifications considered requisite by Vauban, and quoted above; but the permanent intrenched camp of modern times is not necessarily in conjunction with a fortified place.

The intrenched camp at Lintz, already explained in the Corps Papers, is one of the most remarkable for its extent and novel description of defence, as projected by the Archduke Maximilian. Without following so expensive a system, it is proposed to suggest a description of work which will fulfil all that is desired to form a permanent intrenched camp, which would serve to protect the frontiers of Canada, and, fixed in central positions, support the defensive works on the bays and coasts of Great Britain and Ireland; each camp sufficiently extensive to contain from 15,000 to 25,000 men.

The project here offered consists in fixing a number of masonry réduits from 1200 to 1500 or 2000 yards apart, each capable of containing a garrison of 100 men and ten pieces of ordnance, of which six may be on the summit, and

four casemated; and placing these réduits on the sides of a parallelogram or circumference of an ellipse, of about two miles by one in extent, would be capable of enclosing a larger force, from 15,000 to 25,000 men.[14]

Plate VII. explains the construction of the masonry réduits to form the permanent part of the camp.

The réduit may or may not have a ditch and counterscarp, with a draw-bridge and couvre-porte, if necessary, according to the nature of the position and ground. These permanent works to be connected eventually by retrenchments, abattis, escarpements, and inundations, as circumstances dictate. The expense of the masonry réduit, it is conceived, will not exceed £10,000; the cost of the retrenchments and the camp itself must depend upon localities, and the description of camp, whether the troops will be under canvass, hutted, or temporary barracks.

It is presumed that an intrenched camp of this nature could not be forced or taken without heavy artillery, and the process of a siege; and as the object of this description of fortification is only to gain time and concentrate the resources of the country it is destined to cover, a siege operation and detention of fifteen or sixteen days should accomplish all that can be expected; for it is not supposed that an intrenched camp can of itself protect a country, any more than a strategetical or other description of fortress, without an army in the field.

VI. OBSERVATIONS ON FIELD FORTRESSES, OR PLACES DU MOMENT.

"*Places du moment*, qui pour être construites en terre, dans le courant d'une campagne, n'en sont pas moins réellement des places de guerre."—*Essai Général de Fortification*, livre v. chap. ix.

The judicious emplacement and construction of places du moment must be of interest in our Service, as there are so few fortified places in the British dominions. Yet they have all the properties and consequences of fortresses, of which they may be deemed those of the least value. But if we go back to the Peninsular War, subsequent to the publication of the 'Essai Général,' we shall

14 It is not now usual to connect the intrenched camp, whether permanent or otherwise, with an enclosure, but there should be intervals between the retrenchments for the movements of the troops, and its great extent is a reason for its not being supported by an enceinte continue, for which the army within must be the substitute.

find that the place du moment, or field fortress, was of great importance; for example, Saragossa, constructed by the Spaniards,—Burgos and Salamanca, by the French,—and Abrantes and Peniche, by the English. Bousmard considers these works under the term of intrenched posts, executed with sufficient care to prevent a coup-de-main, and to oblige an enemy to go through all the preliminaries, and frequently the whole process, of a regular siege,—in reality, fortresses.

Works of this nature should only be undertaken when there is ample time to execute them with care and solidity, and when local circumstances favour their construction. Among the latter advantages, an old town wall,[15] large substantial buildings whose walls cannot be destroyed by field artillery, and which can be well secured by blindages,—inundations, escarpments, and abattis, serve as excellent accessories in front, to be connected by substantial redoubts, protected by blockhouses and fougasses.

To render this description of fortress of value, it must be well armed, with at least 12-pounders and 6-inch howitzers and mortars: light traversing platforms should be placed in the salients, and ground platforms in the flanks; expense magazines provided for, with a sufficient supply of water, provisions, and stores.

Places du moment ought to be of sufficient extent to require at least 1800 men, or they become mere field-posts; they are applicable to defensive and offensive operations, where it is obvious what site to choose and what importance it is desirable to give to the works in relation to the object, the number of troops, and provisionment to spare. Regular fortresses are constructed at a vast expense, and the position not always applicable to the circumstances of the moment.

Burgos,[16] situated on the right bank of the river Arlanzon, and at the junction of the roads to Reynosa, Valladolid, and Madrid, was fortified and converted into a field fortress by order of Napoleon in 1807, and improved in subsequent years. The site taken up was merely rising ground in rear of the town, with a château on one extremity of the knoll and a church at the

[15] "Ce sont ces places du moment, si je peux m'exprimes aussi, qui ont soutenu les siéges les plus vigoureux, c'est qu'un commandant qui fait réparer une mauvais enceinte imaginer les obstacles, les faire naitre, les avancer, pour ainsi dire sur les pas de l'assiégeant."—*Guibert*, '*Essai Général de Tactique*,' second part, chap. xvi.

[16] *Vide* Belmas' Sieges; and for a Plan of Burgos see the Corps Papers.

other, about 300 feet above the level of the river. The summit was intrenched by three enclosures: the first, or inner line, comprising the castle; the outer one taking the form of the hill, with such flank defences as could be formed; and the second or middle line nearly parallel with the outer, having the church fortified for its support. On the north-east front, on a connecting ridge, was placed a horn-work 550 yards in advance: this advanced work and the inner line were revetted; the other works were of earth palisaded, but the sides of the hill were in some places scarped precipitously, and partially revetted.

This field fortress, or place du moment, was armed with twenty pieces of different calibres, of which three were 16-pounders. The garrison consisted of 2000 men, but the accommodation for them was very limited; just sufficient bomb-proof for the ammunition and sick and wounded, and the supplies were very bad. Yet, with many essential defects, it stood a siege of thirty-three days without being taken; having served as a rallying point to the French army of the north, after the battle of Salamanca; and during the Peninsular War, from 1807 to 1813, it was one of the principal posts of communication, entrepôt, and support with France, and served every purpose of a fortress of the third class.

Saragossa, a city containing 50,000 inhabitants, imperfectly surrounded by a brick wall only thirteen feet high, served as a fortress of the first class to the Spaniards, although, in fact, a place du moment; and when the French entered Spain in 1807, Saragossa was little better than an open town, (see Plan VI. annexed to this Paper.) But, taking advantage of the numerous public and religious buildings of massive structure, situated at the extremity and outskirts of the town, which were loopholed and blinded, and the judicious emplacement of batteries, and connecting these by intrenchments, this place stood two sieges; the first with success, and the second an attack of eight weeks, against an army of 50,000 men, (see Belmas' Sieges); and if the Spaniards had had an army in the field, which the protracted defence ought to have given an opportunity to organize (and which is essential to insure the advantages and utility of field fortresses), the consequences of the second siege would probably have been different.

VII. THE APPLICATION OF FORTRESSES, INTRENCHED CAMPS, AND PLACES DU MOMENT, TO THE DEFENCE OF THE METROPOLIS, IN CONNECTION WITH THE RAILROADS LEADING TO THE SOUTHERN COAST OF GREAT BRITAIN.

"Les ressources défensives des nations ne sont pas aujourd'hui un mystère pour personne." [17]

The following suggestions are not offered with any idea of their being realized, but to draw the attention of the corps to fortifications of a large and extensive nature; as the time may not be distant when a vast expenditure will be incurred upon works of defence, instead of those termed by the French *ouvrages défensifs usités chez les Anglais.*[18]

On the application of works of defence for the security of the metropolis, it is not proposed to consider the probability or impracticability of effecting a debarkation with a large army upon the southern shores of England, which must be contingent on winds and weather, however powerful our maritime force may be; but merely to take the possibility as a proposition for a system of defence.

Being a question purely hypothetical, it is assumed that a foreign force of about 30,000 men had landed and intrenched themselves until reinforced, and when this force sufficiently accumulated, they would advance on London, which is three days' march for the light cavalry to reach the suburbs; and it is likewise assumed that this would not be attempted with less than 100,000 men. As it is not possible that works of defence of any value could be executed between the debarkation of the enemy and its entry into London, a period of about ten days,—and, as it has been before observed, the intermediate country offers no obstacle to his advance, but every facility, by the excellent roads,—it is proposed to imagine a system of defence capable of meeting such a contingency, and resisting successfully the approach of this hostile force from the southern coast between Dover and Portsmouth, calculating that there is a disposable military force spread in the United Kingdoms.

The position which it is conceived would form an advantageous line for defensive and offensive operations to cover London, to be fortified in several points with field and permanent works, extends from Woolwich to Windsor, about 30 miles, parallel with the southern coast. The line of operations to the coast will be on an isosceles triangle, of which London Bridge may be con-

[17] 'Essai sur la Fortification moderne,' par M. le Capitaine Emile Maurice. [18] Ibid.

sidered the apex, and the sides 70 miles; and at the extremities of the base, along the coast, are the fortresses of Dover and Portsmouth, distant from each other 90 miles.

The advance of an enemy, therefore, (London being the objective point,) would be stopped by the proposed defensive position, having the garrisons of Dover and Portsmouth hanging on their rear.

The points to be fortified on the line proposed are,—

1. Woolwich, permanently.
2. Near Croydon, a permanent intrenched camp.
3. Kingston, converted into a strategetical fortress.
4. Windsor, into a place du moment.
5. Several intermediate points, intrenched, between Woolwich and Windsor.

1. Woolwich might be converted into a fortress of the first class, with a hexagon of the largest scale, constructed on Shooter's Hill, as a citadel to be connected with the Thames on one side by a range of defences on the west, enclosing the village of Charlton, and by the ravine and enclosure of Cholmondley House to the Marshes, and another range of works east by Plumstead Common and Marshes, so as to effectually enclose the Dockyard on one side and the Arsenal on the other. These fortifications would require 15,000 men to defend them, and would probably cost £1,500,000. Woolwich would be thus a vast dépôt, tête-de-pont, and support to the defensive position, whereas at present the immense stores, dockyard, arsenal, and military buildings, are entirely without protection.

2. The intrenched camp, which it is conceived might be constructed near Croydon at the junction of the railroads running south and south-east of London, the works formed upon the principle suggested in Section V. of this Paper, having the masonry réduits built (as the fortress of Woolwich would be) probably in time of peace, and the ground purchased and taken and marked for the camp. As it would be inconvenient to place the troops under canvass, and advantageous to have the means of assembling an army on the breaking out of a war, barracks of a light construction may be built, similar to the temporary buildings erected during the last war, but even less expensive:[19] this

[19] This construction might be of framed-work of timber of light scantling on a low masonry foundation, brick-nogged and weather-boarded outside. I found this description of building in Newfoundland weather-tight, and sufficiently warm: in this climate, asphalte floors would suffice for

permanent intrenched camp for 25,000 men of all arms, enclosed by retrenchments suited to the nature of the ground, which the troops could throw up in a few weeks, having the masonry réduit for support, and the barracks for their accommodation, already executed. Such a camp of itself, it is conceived, *would be an impediment to the advance on London; the first expenses of the* buildings being about £400,000.

3. But with the strategetical fortress which it is proposed to construct at Kingston on the Thames, for 15,000 men, the advance of an enemy would be scarcely practicable between this post and Woolwich, covering the south of the capital. Kingston fortified, in the first instance, upon the principle suggested in Section IV., à cheval on the Thames, and further retrenched, when necessary, with advanced works which may be advantageously thrown up, enclosing the environs of the town, would be converted into a fortress of the first importance, the probable cost of which would be £1,000,000.

4. As the line between Woolwich and Kingston may be turned on its right, it has been proposed to continue the defensive position to Windsor, and to fortify the environs of the Royal residence at the last moment, and to convert Windsor, including Eton and Datchet, into a field fortress for 15,000 men: the country affords great resources for works of that character, the forests serving for abattis, the low ground for inundations, and the castle as a point of support.

5. In the event of the southern coast being threatened, there are several intermediate points which should be fortified between Woolwich and Windsor, such as Southend, between the former and Croydon, in front of Wimbledon, and all the bridges between Kingston and Windsor.

The position thus described to cover London, which may be turned by a flank movement, could be extended to Marlow and High Wycombe by placing an intrenched camp at the latter, and fortifying the bridges over the Thames to the former inclusive.

It is conceived that no invading force would make London the objective point, except between Yarmouth and the Thames on the east, and that river and

temporary barracks; the roof covered with tiles, slates, or zinc; no ceilings or plastering of any kind, but the tiles or slates to be rendered inside; the chimneys, doors, and windows, and fitments, common to all barracks. For bedsteads I would propose the half-billet trestles now used in Ireland for half-billet stations; they stand about 8 inches off the ground, are clean and handy, easily obtained, and of trifling expense.—G. G. L.

Portsmouth on the south; and all attempts north and west of those points would be solely for predatory purposes, assuming that an enemy would take into consideration the difficulties which occur of carrying on offensive operations any distance from the point of embarkation, with the common vicissitudes of a fifteen hours' voyage instead of three or four.

CONCLUSION.

The following conclusions may be drawn in considering the fortified position or frontier on a small scale to cover London, all bearing on its defence.

First, the command it gives to all the railroads [20] to the south and western coasts, which may be brought to one uniform guage, and connected with the proposed fortified posts of Woolwich, Croydon, Kingston, and Windsor, by direct and lateral branches; each fortress having an establishment of locomotives and carriages for the conveyance of the disposable forces.

Secondly, the application of the electric telegraph in connection with a central point of the position with those on the coast, so that in a few minutes notice would be given for the movement of the troops on the approach of an enemy.

Thirdly, the absolute command which the position gives to the disposable forces which form the garrisons of the fortified posts, to dispute a debarkation and advance, which would be conveyed in two hours to any part of the southern coast, leaving the sedentary force, composed of the militia and volunteers, to protect the posts.

Finally,[21] the fortified line serves as a point of retreat and support, and the

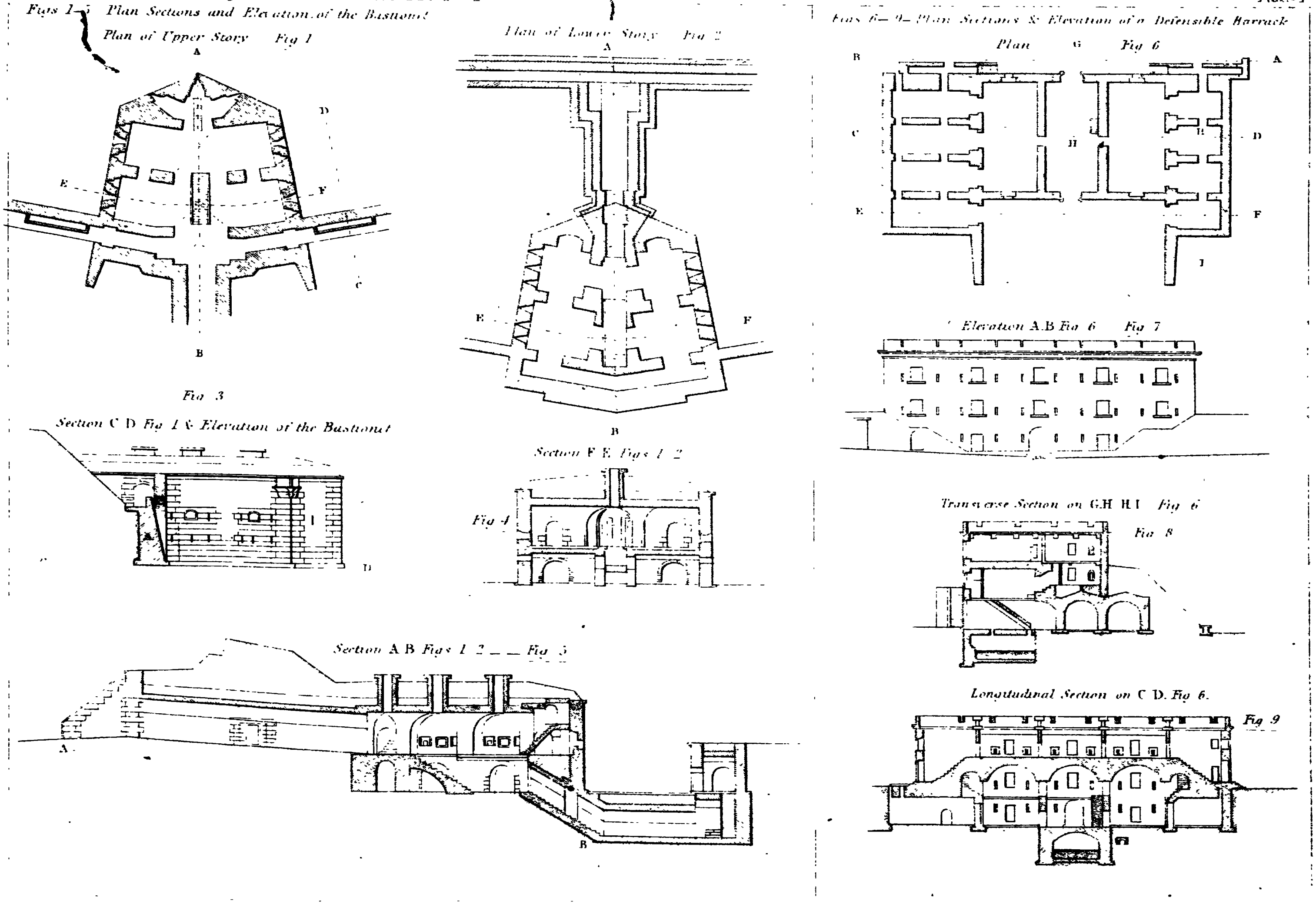
[20] The rapid progress in the improvement of locomotive carriages renders suggestions for the construction of carriages for the transport of troops difficult, if not superfluous: it is conceived, however, that the principle of Bianconi's cars, used in Ireland, would serve for infantry; those for cavalry and artillery require consideration; and it might be better, perhaps, except for supplies, to station that force in central points not far from the coast. These Bianconi cars, in which the men sit back to back, the centre part serving for the packs and provisions, could be constructed to carry thirty men on each; and twenty-five carriages would take the effective force of a regiment, moved by one engine,—the whole costing about £3000. Twenty of these equipments would take 30,000 infantry to the coast in two hours, supposing that there was an establishment of locomotives at Woolwich, the intrenched camp at Croydon, Kingston, and Windsor.

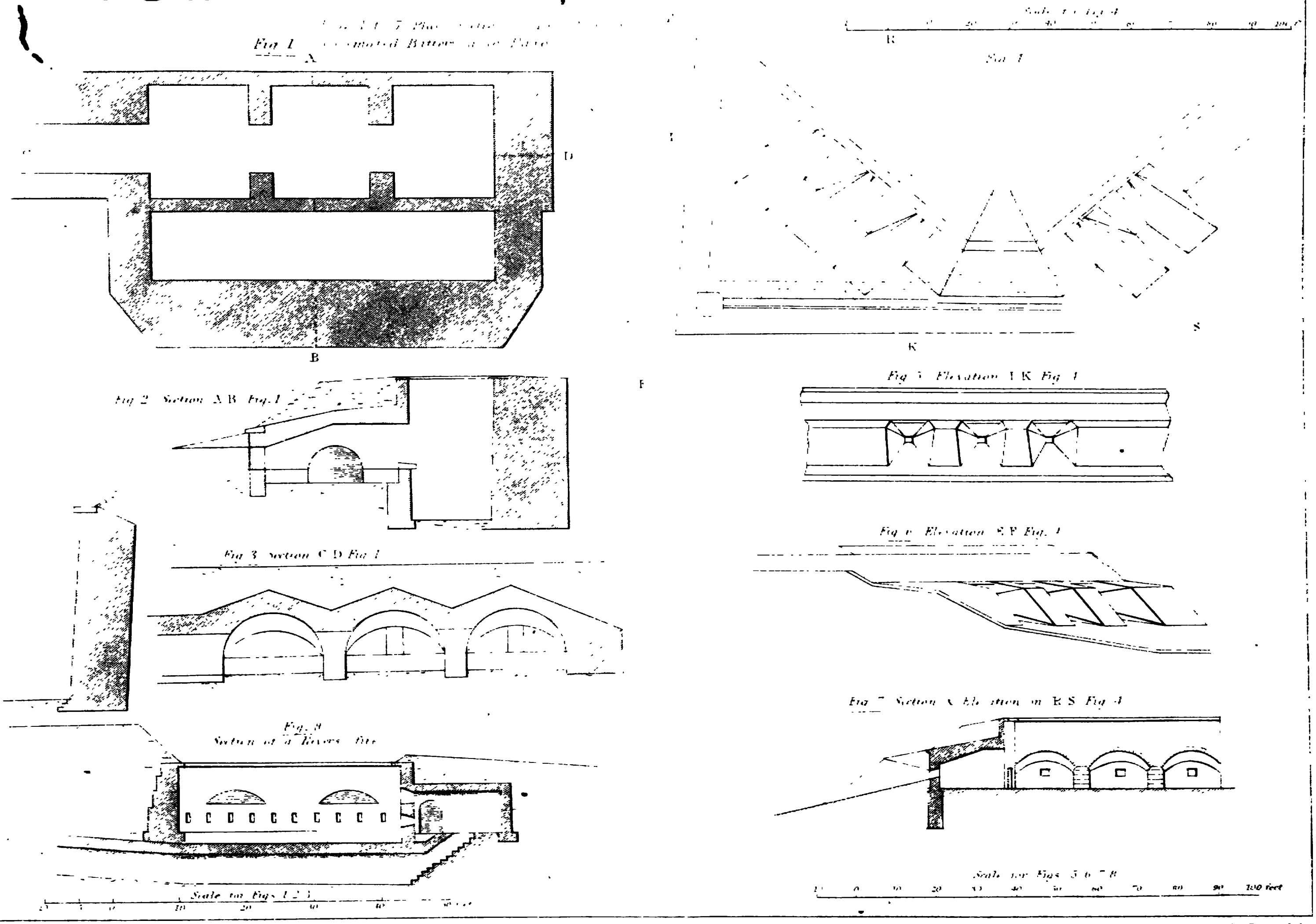
[21] Resuming to a part of the first section of this Paper, quoted from Guibert, so applicable to the subjects here offered to the corps as worthy of observation, and perhaps not an unprofitable study, he observes—

rallying and collecting points for the whole disposable forces of the United Kingdom, and a field of battle between either of the posts, if, in a defensive position, the last effort is made to protect the capital.

Dublin, 1st Feb. 1846.

"Pour être tacticien, il faut connoître la science des fortifications; et que, pour être ingénieur, il faut être tacticien. La première partie de cette conséquence, est admise et reconnue dans le militaire, sans que cependant les officiers s'éclairent en conséquence. La seconde semble ne pas l'être parmi les ingénieurs; car généralement ils ne savent ni comment les troupes manœuvrent, ni comment on doit les conduire: ils ne veulent pas même le savoir; regardant leur art comme le premier des arts, ils dédaignent toutes les autres branches de la science militaire."—*Essai Général de Tactique, par Guibert.*


Figs 1–5 Plan Sections and Elevation of the Bastionet
Plan of Upper Story Fig 1
Plan of Lower Story Fig 2
Fig 3
Section C D Fig 1 & Elevation of the Bastionet
Section F E Figs 1 2
Fig 4
Section A B Figs 1 2 — — Fig 5
Figs 6–9 Plan Sections & Elevation of a Defensible Barrack
Plan Fig 6
Elevation A.B Fig 6 Fig 7
Transverse Section on G.H H.I Fig 6
Fig 8
Longitudinal Section on C D. Fig 6.
Fig 9

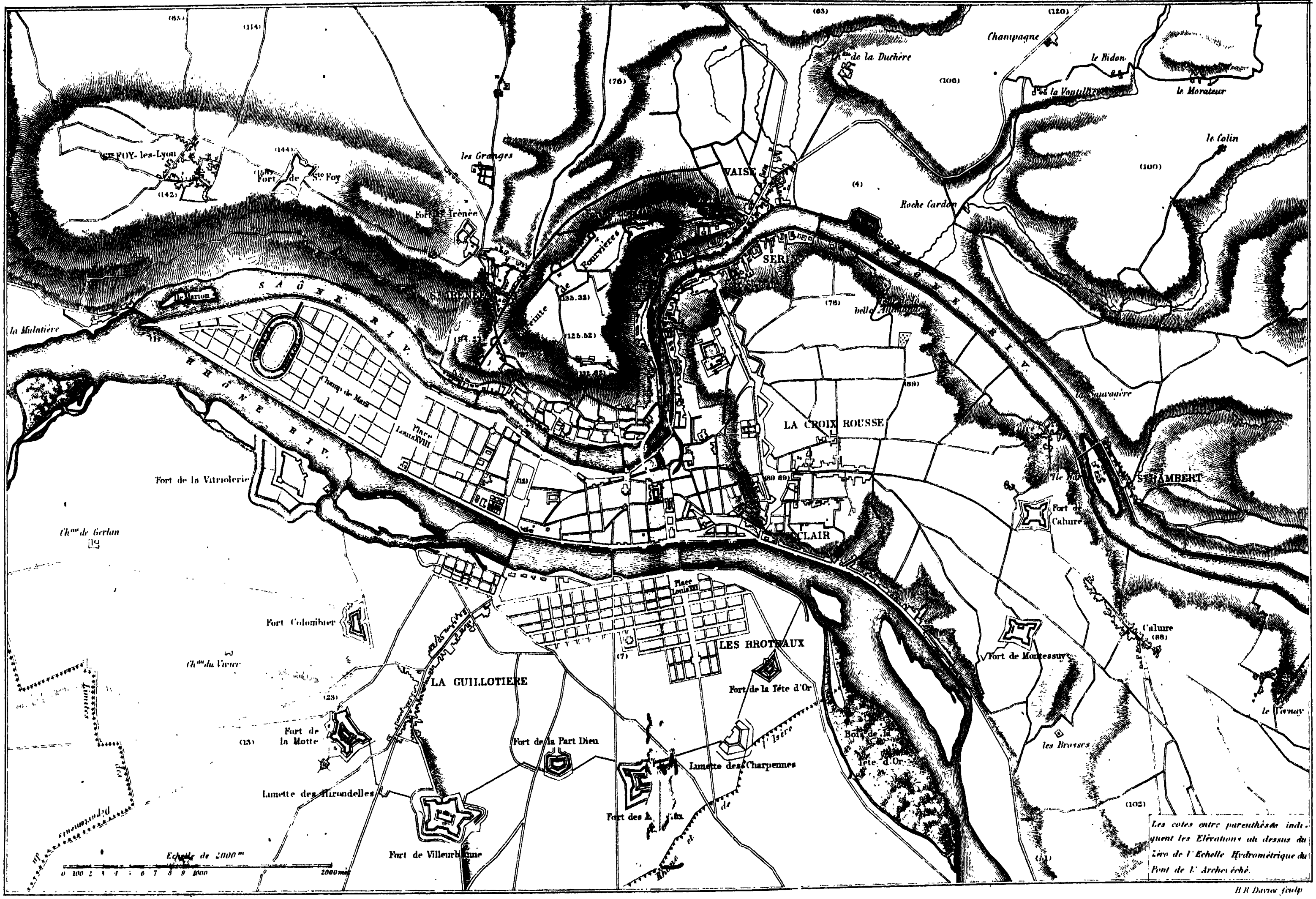


B.R.Davies sculp

From Maurice's Essai sur la Fortification Moderne

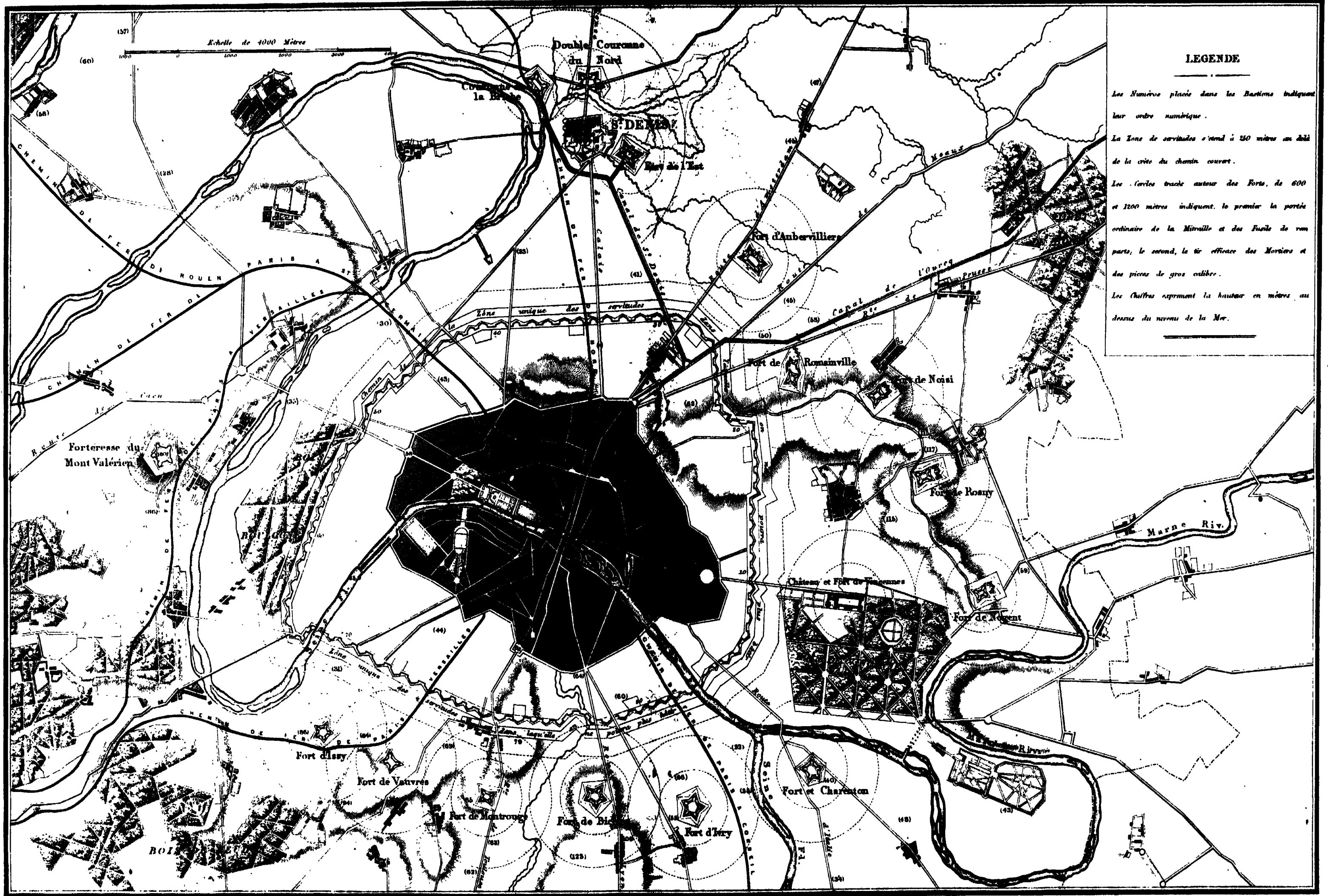
PLAN OF LYONS.

Plate 3.

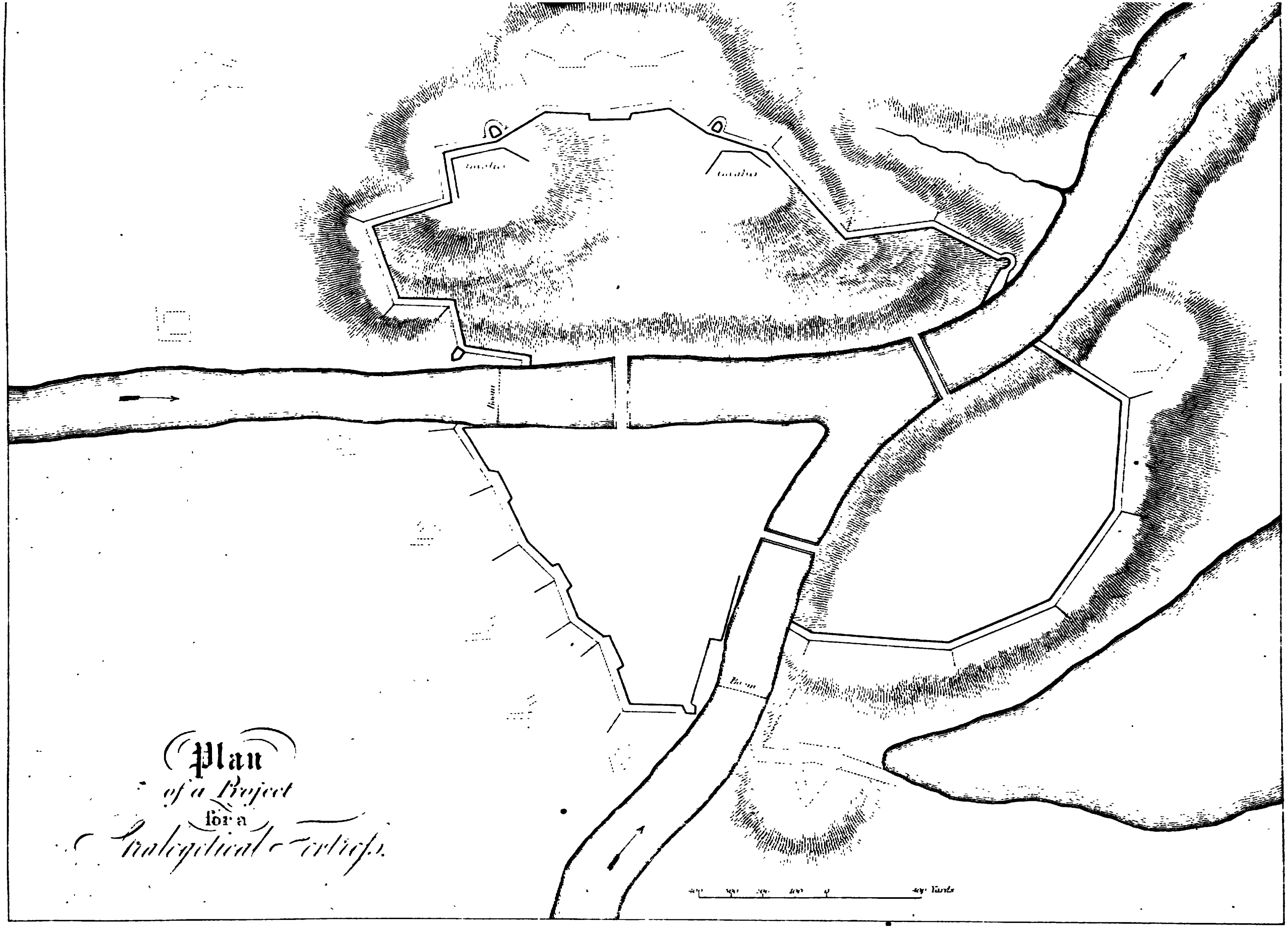


B R Davies sculp

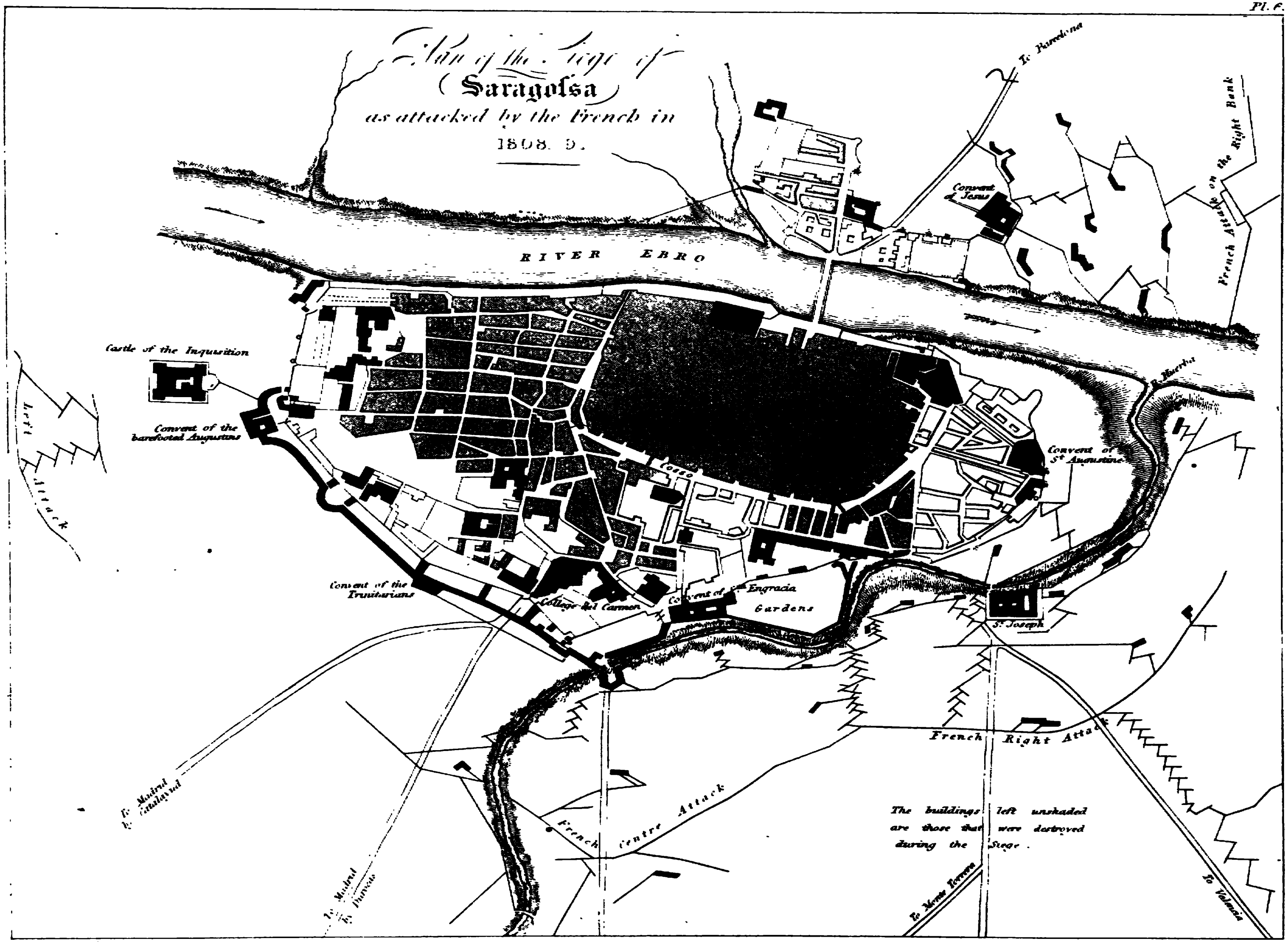
London John Weale Architectural Library, 59 High Holborn



London, John Weale, Architectural Library, 59 High Holborn.


Plan
of a Project
for a
Strategetical Fortress.

Pl. 6.



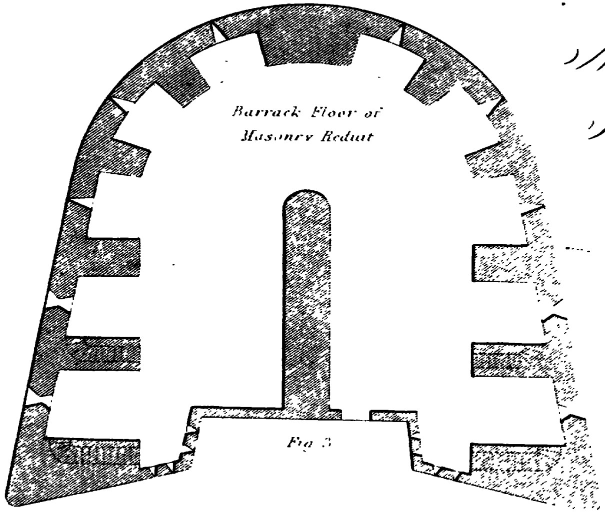
From Belmas' Sieges.

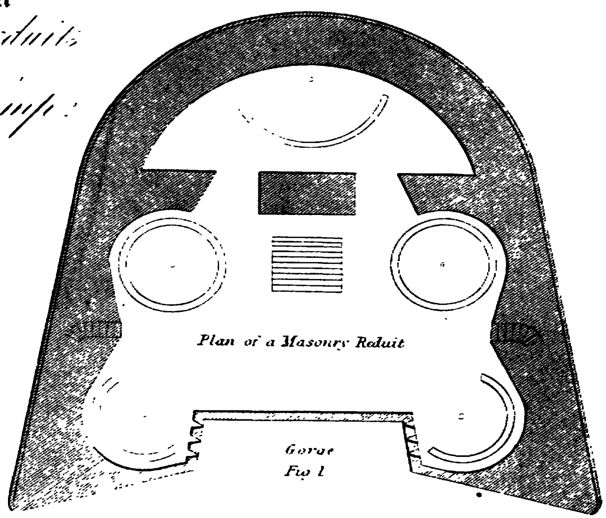
B.R. Davies sculp.

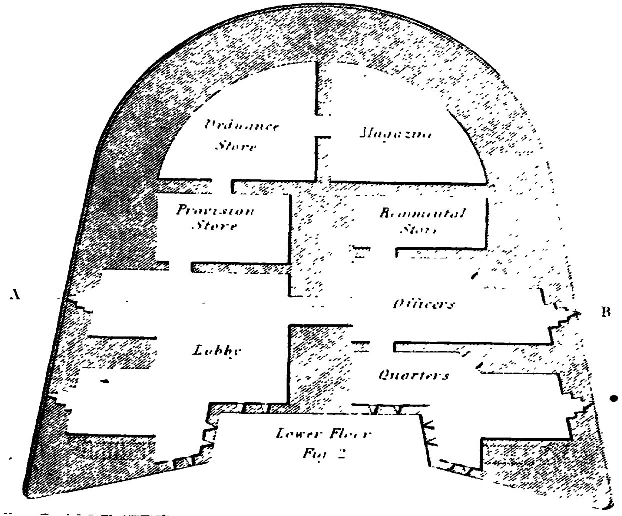
London John Weale Architectural Library 59 High Holborn 1847

Plate 1

Design for a Masonry Reduits for an Intrenched Camp.

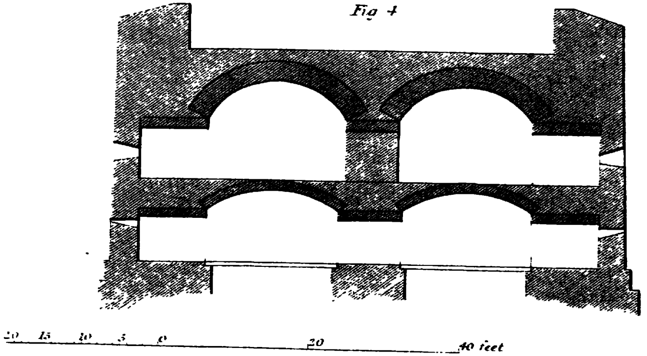






Section of Masonry Reduit on line A B Fig. 2.

Fig 4



G. G. Lewis des[t] & del[t]

London ... 1847

B R Davies. sculp

II.—*Account of the Battle of Meeānee,*[1] *with a Plan. By Major* Charles Waddington, *Commanding Engineer, Scinde and Beloochistan.*

On the afternoon of the 16th February, 1843, after a fatiguing march of twenty-one miles from Halla, the British force, about 3000 strong, under Major-General Sir C. J. Napier, K.C.B., encamped near the village of Muttāra, seventeen miles north of Hydrabad.[2]

Muttāra lies within a mile or two of the Indus, and Major Outram, who had been ineffectually negotiating with the Scinde Ameers, now landed here from the *Planet* steamer, accompanied by his escort, the light company of H. M. 22nd regiment.[3] He confirmed the report already received by the General at Halla, of his having been attacked on the preceding morning at Hydrabad. It appeared that the Residency (which lies on the left bank of the Indus, three miles south-west of the city) had been surrounded by a large body of cavalry and infantry, headed by one of the Ameers, Meer Shahdad Khan. A gallant defence had been made by his escort during four hours, when, ammunition failing, they had been compelled to retreat to the river. Here they were received on board the two steamers, *Planet* and *Satellite*, which conveyed them to Muttāra, as above stated.

Major Outram brought with him the intelligence that the Beloochees had assembled in great force, and posted themselves in the shikargahs[4] which intervene between Muttāra and Hydrabad. It was thought that by setting fire

[1] Meeānee is the name of the district between the Indus and Foolailee rivers.

[2] This force was about 3000 strong, comprising 1100 cavalry and 12 field-pieces, viz.:—9th Regiment Bengal Light Cavalry,—detachment of Poona Irregular Horse,—Scinde Irregular Horse,—Bombay Camel Battery, 9-pounders,—Bombay Horse and Mule do., 6-pounders,—detachment of Madras Sappers,—Her Majesty's 22nd Regiment of Foot,—1st Grenadiers, Bombay Native Infantry,—12th Bombay Native Infantry,—25th Bombay Native Infantry.

[3] Commanded by Captain Conway.

[4] The shikargahs are forests enclosed for the preservation of game.

to these woods, the enemy would be driven to the plain, and a party of 200 Sipahees was embarked the same evening with Major Outram and other officers, on the two steamers, to co-operate with the sailors in carrying this scheme into effect. The design, however, failed; for though the woods were partially fired, the scene of action on the 17th was too far distant to be affected by this stratagem. The Beloochees, it was said, had shifted their ground during the night, but it is more probable that we were mistaken as to the position of the shikargahs which they occupied.

At four o'clock on the following morning, 17th February, the troops again marched, the Scinde Horse, under Captain Jacob, leading. They were followed by the Sappers under Captain Henderson, with a working party of 100 Sipahees to prepare a passage for the guns. The numerous canals which intersect this country had made the arrangements for crossing them a nightly work of great labour, and much impeded the progress of our artillery. We usually cut down the banks of the canals, throwing the earth into the centre; but as camels cannot pull up hill, it was necessary to make the ascents very gentle. On this morning, a delay of more than an hour occurred in forming the road over two large canals not far from Muttāra. Beyond these, however, it was found that the Ameers had anticipated our labours, the roads being already prepared for the passage of their own artillery.

A march of seven miles brought the advanced guard to the Foolailee, which is a small branch of the Indus, filled during the inundations of that river, but at this time of the year dry. Along its eastern bank the road continued for a couple of miles, passing, in quick succession, several small villages interspersed with groves of trees. Near the second of these, the silence of the march was first broken by the sound of a distant cannon. Sir Charles instantly formed up the infantry of his advanced guard behind a small canal, disposing the Scinde Horse in the bed of the Foolailee, and unlimbering the two 9-pounders which accompanied him. Shortly afterwards a squadron of the Scinde Horse was dispatched across the Foolailee to skirt round a shikargah on the opposite bank, while the remainder was sent to the front to reconnoitre. It was soon ascertained that the enemy was certainly in the latter direction, and the General again moved on, till he arrived at a village where the road to Hydrabad leaves the bank of the river.[5]

[5] These roads are merely beaten tracks, and the bed of the river is as much used as any other.

Close on the General's right at this time was the dry bed of the Foolailee, having its course nearly south; and, as far as the sight could reach in that direction, its further bank was enclosed by a mud wall, which bounded a dense shikargah. Directly to his front rose the last of the string of small villages before mentioned (Zāhir Bāhirchy Kā Gote). Half a mile again beyond that, another vast enclosed shikargah extended at a right angle from the near bank of the Foolailee about a mile, and overlapped his left flank, though somewhat receding from it.

Two squadrons of the Scinde Horse, under Captain Jacob and Lieutenant Russell, meanwhile continued their advance, turning off obliquely to the left till they found themselves within half a mile or less of the enemy's guns. Here they drew up in line, and were afterwards joined by the squadron which had been detached to examine the shikargah on the other bank of the Foolailee. In this position the whole of this gallant corps remained, observing the enemy's movements and exposed to his fire, till the final advance of the British line.

The General again moved forward for a thousand yards or so, along a beaten track which appeared to lead round the left skirt of the shikargah in his front. Here finding himself in sight of the enemy, and within long range of his artillery, he decided on waiting for the main column of his force. This column was far behind, as the guns had been much impeded in their progress by accidents arising from the badness of the road.[6] The delay thus caused was considerable, and gave time to examine attentively the enemy's position.

Immediately in our front, the top of the shikargah wall was thickly studded with matchlock men, more particularly at its eastern or receding end. Extending from this to the enemy's right, was seen a dense mass of his infantry surrounding two conspicuous flags, and supported by large bodies of horse in its rear, while in front of it were posted numerous pieces of cannon. Some of these, more advanced than the rest, had been firing on the Scinde Horse, and now directed their shots,[7] though from a great distance, on the General and his advanced guard. The right of the enemy's infantry rested on groves of trees which concealed a village, and the whole of this chosen ground was occupied in great strength.

[6] The store carts of both batteries had had their pintle-eyes broken this morning, and a waggon of the camel battery had been upset.

[7] These balls were of beaten iron, and weighed 5 or 6 lbs. each. The Ameers' artillery was under the direction of an Englishman.

Such was the formidable position taken up by our yet untried adversary, and which the slow approach of the British column allowed ample time to observe and discuss. It was generally thought that about 8000 infantry and 3000 cavalry were at this time visible from the General's station, as yet distant nearly a mile from the eventual scene of action. But the full strength of the Beloochee was not manifest from this place of observation; for it could neither be seen from thence that he held on his right a village strongly protected by trees, and canals and walled enclosures, nor that along and behind the whole of his line ran the bed of the Foolailee river, at right angles to its former course.

At length the arrival of the main column enabled the General to advance. The same order of march was preserved, and, following the direction of the beaten road, which edged off to the left, the column was not halted till within 300 yards of the shikargah wall. This wall, as before mentioned, had been studded with Beloochees, but was deserted on our approach after some distant discharges of matchlocks; and as it was eight feet high, without loopholes or banquette, it afforded in fact no advantage of offence to the enemy, though it screened him from our fire.

The head of the column, which arrived left in front, was directed on the first distant tree standing to that flank, nearly at right angles with the road, and, as soon as it had taken up sufficient ground, the column was again halted and wheeled to the right into line. The whole of the guns under Major Lloyd, four 9 and two 6-pounders, two 24 and two 12-pounder howitzers, with the Sappers, were placed on the right of the infantry towards the shikargah. Behind the right, the 9th Bengal Cavalry, 350 strong, was in reserve. The Scinde Horse, about 500 sabres, were in the position which they had occupied for the last hour, 300 yards in advance of the left of the infantry line. They now formed column near the shallow green bed of a dry water-course, bordered by scattered trees, and leading directly forward to the village of Syud Sooltan Shak Ki Wustee, or Kātree,[8] which flanked the enemy's right. From right to left the order of the infantry regiments was as follows:—first, H. M. 22nd regiment; next, the 25th and 12th regiments Native Infantry; and last, the 1st Grenadiers Native Infantry; mustering altogether, when joined by their details from the advanced guard, 1350 bayonets. The Poona Horse, under Captain

[8] Kātree is more properly the name of the district.

Tait, with 200 of the Grenadiers and two 6-pounders, had been left as a rear-guard, and did not come into action.

Before the British line there now lay a narrow plain, dotted with low sandy hillocks and camel bushes, and extending in front to the Foolailee, a distance of 1100 yards. Bounded on the east by the shallow green nullah, the trees and the village before described, and beyond these by an impassable canal,[9] it was shut in on the west by a continuation of the shikargah wall, which, taking an abrupt turn from its north-east corner, ran thence for a distance of 600 yards to the Foolailee, in a south by east direction. The front of this contracted space measured, in a straight line, only 700 yards from the shikargah wall to the village, and this was to be the field of battle. The enemy had selected it with judgment, for while the abrupt banks of the Foolailee afforded him a strong retrenchment, the British artillery and cavalry were greatly embarrassed by want of room, as will appear in the sequel of this account.

As soon as our line had been carefully dressed, and skirmishers thrown out, the guns were moved forward 200 yards, and our first fire (of round shot) opened on the enemy's batteries a little before eleven o'clock. H. M. 22nd formed up on the left of the artillery, and the remaining regiments were placed in échellon to the rear at 20 paces distance. Our guns, being found too distant to silence the enemy's batteries, were again advanced about 250 yards; and the enemy's fire, which, though briskly kept up, had not been very destructive, now evidently slackened under the rapid and well-directed discharges of the British artillery. At this time an opening was seen in the shikargah wall close to our right flank, and the grenadier company of the 22nd regiment, under Captain Tew, was detached to clear the wall. This was done by entering the shikargah, the jungle for some distance from the wall being thin and open. Captain Tew was almost immediately shot dead, and the company otherwise suffered, but the skirt of the shikargah was cleared for the time by these brave men.

A third halt was made at 300 yards from the Foolailee; and while some of the British cannon swept the outside of the shikargah wall with grape shot, and others kept down the enemy's fire, and at last silenced it, the infantry line, still formed in close échellon of regiments, was dressed in preparation for its final advance.

[9] This canal was dry, but the sides had been recently scarped, probably in the process of cleaning it.

The word to advance was given: H. M. 22nd, our only European regiment, led the échellon, and as the bugles sounded, moved on in the most perfect order. A galling fire from numerous matchlocks was received with firmness, and in due time returned, though at first without much effect. Sheltered by the steep bank of the Foolailee, the Beloochees rested their matchlocks and took deliberate aim. In its turn the 25th regiment N. I. became engaged, and then the 12th and Grenadiers. On this flank the enemy was even more strongly posted than on our right, for the water-cuts and walls of the village protected him. His guns meanwhile had been abandoned when the British troops advanced, and were most of them already in our possession. But as the distance lessened, the more daring of the Beloochees, fresh and impatient for the fight, put aside their matchlocks. With sword and shield in hand, they rose from their hiding-places, and in more than one impetuous onset, shook and forced back the British line. Twice or three times were the 12th N. I.[10] beaten back, and as often were they nobly rallied by their officers. Brevet Major Jackson of that regiment, dismounting from his horse, thus sacrificed his life. Advancing to the front, followed by only two havildars, this lamented officer, after a short combat, fell beneath the sabres of the enemy. The 1st Grenadier regiment,[11] driven back with the 12th, fell into some confusion, and appears to have taken but little share in the action. Major Teasdale, commanding the 25th, was killed while animating his Sipahees, who gave ground in an alarming manner before their fierce opponents.[12] Lieut.-Colonel Pennefather, commanding H. M. 22nd, was shot through the body, and Major Poole succeeded to that command. Even his stout Europeans could not keep their ranks unmoved under the furious attacks of the Beloochees. Defending themselves more skilfully with their bayonets than the Sipahees, they yet swerved back from the sharp sabres of their desperate foes, many of whom were excited with bhang[13] or opium. Lieut. Mac Murdo, Assistant Quarter-Master General, his horse having been shot under him, killed a Belooch chief hand to hand, and made prize of his gold-handled sword. Still our brave officers and soldiers

[10] Commanded by Major Reid.

[11] The 1st Grenadier regiment mustered less than 200 bayonets with its colours.

[12] Captain Jackson, brother of Major Jackson, of the 12th, took command of the 25th on Major Teasdale's death.

[13] Bhang is a decoction of hemp-seed.

continued to fall;[14] and now Sir Charles Napier, seeing the obstinacy of the fight, and doubtful of its issue, pushed his horse through the ranks of H. M. 22nd, and waving his cap, cheered on that gallant regiment. In the same manner, regardless himself of danger, he encouraged the 25th N. I. to advance. At this time it was no doubt the General's wish to drive the enemy from the bed of the river by a vigorous charge, but this intention was not carried into effect. The bayonet was but little used except in defence, and it shortly became evident that the fire of the matchlock and the glancing of the keen sabre were less and less frequent, while the continued and destructive roll of musketry, delivered from the edge nearly of the river bank, levelled every living being before it.[15] For upwards of an hour did this mortal struggle endure; and when at last the British line descended into the river, it was but over crowded heaps of dead and dying. The pouches and cotton clothes of nearly all these men had taken fire, probably from their lighted matches, and their scorched and writhing bodies presented a shocking spectacle. Many Beloochee corpses too lay on the bank above, mingled with those of their enemies, mute witnesses of their desperate valour. Quarter was not asked or given. The wounded were shot or bayoneted by our exasperated soldiers, disdaining to yield, and striking at our men to the last.

Meanwhile neither artillery nor cavalry were idle, nor was their aid unimportant in deciding the fate of the day. So contracted was the last position of the guns, that only four of them could be brought into action.[16] One of Captain Hutt's guns, with the assistance of the Sappers, who also broke down part of the wall, was brought round to bear on the shikargah, and did great execution there, while the remaining three swept the Foolailee to the right

[14] *Killed.*

Captain Meade, 12th Native Infantry.	Lieutenant Wood, do.

Wounded.

Major Wyllie, Assist. Adjutant-General.	Ensign Bowden, H. M. 22nd.
Captain Conway, H. M. 22nd.	Ensign Holbrow, 12th Native Infantry.
Lieut. Harding, do.	Lieut. Phayre, 25th N. I., Quarter-Master.
Ensign Pennefather, do.	Lieut. Bourdillon, do.

[15] The bed of the Foolailee is an excavation produced by the current of the river in an alluvial soil, the bank here spoken of being simply the edge of this excavation. The elevated bank alluded to in the official dispatch was confined to a small portion of our front. Below the edge of the bank was a double step or ledge, which was heaped with the bodies of the slain.

[16] Captains Whittlie and Hutt commanded the camel and horse batteries.

and front with a continued deadly discharge of grape shot and spherical case.

During the heat of the fight, orders were sent to the cavalry to force the enemy's right. The 9th Bengal Cavalry had been previously crossed in support of the left of our line, and formed immediately in rear of the 1st Grenadiers. By some misconception of an order, the men of the latter regiment faced to the right about and retreated some distance before their officers could rally them. The Beloochees showed themselves at the same time in numbers from the village enclosures and ravines. Lieut.-Colonel Pattle, of the 9th Cavalry, second in command, had not yet received the General's order to advance, but seeing the necessity of checking the enemy's movement, and partly, as I am informed, on the urgent representation of Captain Tucker, he, after some hesitation, permitted the cavalry to act. The moment certainly appears to have been critical, when the 3rd squadron of the 9th Cavalry, led by that gallant officer, advanced at a trot, passing between our infantry and the village, and driving the enemy into and along the bed of the Foolailee. A body of Beloochees, drawn up in rear of the village, made a stout resistance, from which this brave squadron suffered severely. Captain Tucker received six shots and fell,[17] but Captain Bagett succeeding him, completed the dispersion of the enemy in this direction. The 3rd squadron was followed by the 2nd under Captain Garrett, which supported Lieut.-Colonel Pattle in an attack on the village, while the 1st, under Captain Wemyss, filing between the Grenadiers and 12th Native Infantry, crossed the Foolailee, dispersing the enemy on the opposite bank. Brevet Captain Cookson, the Adjutant, was at this time killed, and three other officers were wounded.[18] Lieut.-Colonel Pattle, with a few men of the 3rd squadron, had gallantly attacked the enclosures of the village, and being afterwards supported by the 2nd squadron, succeeded in partially clearing them. It was the fire from these and the neighbouring canals and gardens which caused the heavy loss of the 9th Cavalry. The Scinde Horse, after an ineffectual attempt to get round the outside of the village, in which they were stopped by a deep canal occupied by the enemy, also descended into the river between our infantry and the village, and rode direct to the enemy's camp. The Ameers had already abandoned it and fled to Hydrabad, but many

[17] It is gratifying to record that this gallant officer recovered from his wounds.

[18] *Wounded.*

Brevet Capt. Smith, 9th B. Cavalry. Lieut. Plowden, do. Ensign Frith, Qr.-Master, do.

brave men were still found there who defended themselves obstinately, and were not cut down without loss to their pursuers. Captain Jacob had his horse killed under him, and deputed Lieutenant Fitzgerald to continue the pursuit, which he did for some distance, till coming on a large body of horse who had not been engaged, that officer was obliged to retire. The Scinde Horse were about the same time recalled to defend our baggage, and a detachment of the Bengal Cavalry held possession of the camp, which was afterwards burnt and evacuated by order of the General.[19]

When the British troops crossed the river, about half-past one P.M., the battle may be said to have ended, but firing did not altogether cease, and multitudes of the enemy still hovered about; nor was it till our guns had been crossed and opened both up the Foolailee and on the village and neighbouring enclosures, that the insurgents gradually dispersed. The General formed his camp on the field of battle, with the baggage in the centre of a hollow square, and the troops slept on their arms.

Thus closed this eventful day. Seldom perhaps has the determined valour of the Beloochees on that occasion been surpassed. The Europeans behaved steadily and bravely, and were no doubt much inspired by Sir Charles's brilliant example. The Sipahees were sustained and rallied by their officers, whose conduct was marked by a noble self-devotion. Without them, they would hardly have recovered themselves as they did, after being more than once driven back. The artillery and cavalry did their duty well, but their actions were in a great degree paralyzed by the confined field to which they were chiefly restricted. It must be admitted, however, that the advance of our cavalry on the enemy's right had probably an important effect in deciding the battle.

Our loss in this engagement was severe, considering the small number of our troops engaged: 62 killed and 194 wounded, of whom 19 were officers (6 killed and 13 wounded).[20] The enemy left upwards of 400 dead in the bed of the Foolailee, and there were probably as many more in different parts of the field

[19] Thirty or forty thousand rupees were found in the camp. The Ameers were said to have brought some lacs of rupees with them.

[20] The number of horses killed on both sides was considerable. The enemy's cavalry was not much engaged, but many of the Beloochees dismounted to fight, picketing their horses in the bed of the river.

and the shikargah, killed by the artillery and cavalry. As quarter,[21] with a few exceptions, was not given, it may be doubted whether the number of wounded who escaped much exceeded the number of the killed. The statements of the Beloochees make their loss much greater, but are probably exaggerated. At the lowest computation, however, the loss of the Beloochees must have been six times that of the British,—a surprising disproportion when we consider their advantage of position, and a plain proof of the superiority gained by discipline, and especially by one of its results, a rapid and well-sustained fire.

The whole of the enemy's guns, 15 in number, the standards, ammunition, baggage, tents, and some treasure, fell into our hands, and the immediate results of the battle were most important. On the two following mornings six of the Ameers surrendered themselves prisoners, and shortly afterwards Hydrabad[22] was taken possession of, and Lower Scinde declared a province of the British empire.

[21] It must be noted that the Beloochees, not expecting quarter, defended themselves to the last, making it nearly impossible to spare them.

[22] Hydrabad was not taken possession of till the 21st, after Major Outram's departure. It was said that there were two millions sterling of public treasure in the fort. If so, a great part of it must have been removed during this delay. The prize-money found was about one-quarter of that sum.

PLAN OF THE BATTLE OF MEANEE,

fought on the 17th February 1843

between the British Force under Maj. Gen.l Sir C. J. Napier, K.C.B.

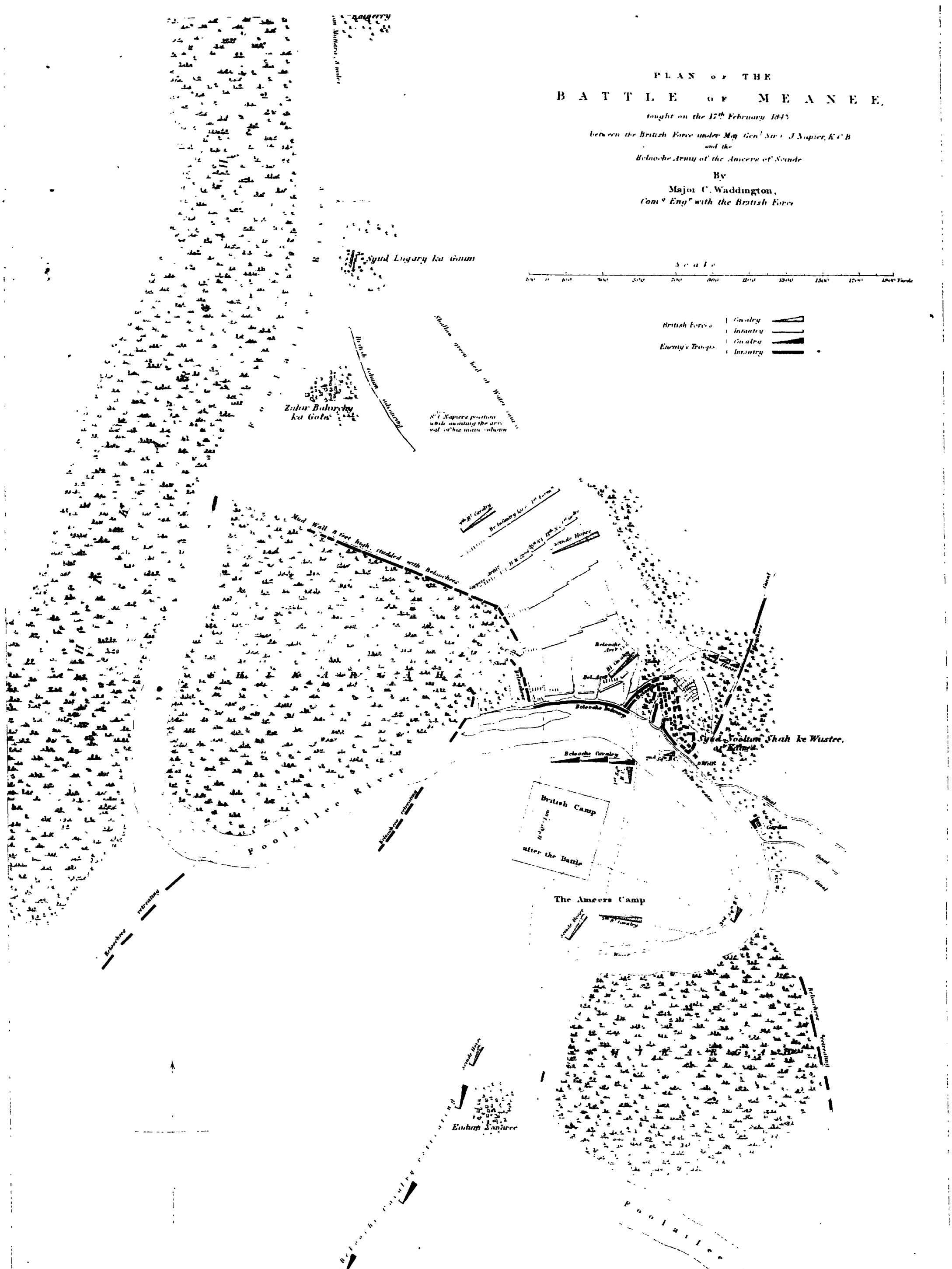
and the

Beloochee Army of the Ameers of Scinde

By

Major C. Waddington,

Com.g Eng.r with the British Force



London, John Weale, 59 High Holborn

III.—*Project of Defence.* *By Captain* Bainbrigge, *R.E.*

Having been lately sent to Germany for the purpose of acquiring a knowledge of the various new systems of fortification now adopted in the construction of works for the protection of that country, I venture to lay before my brother officers, for their consideration, a project of defence which I have sketched out, preserving a general accordance with the views of the German Engineers, though materially differing from any existing works.

It does not involve a large expenditure: it is capable of adaptation to the strengthening of existing bastioned or other works, and is based upon the maxim, that, since fortifications are not capable of benefiting the State in time of peace, like other great military works, such as roads, harbours, &c., and all available means must be directed on the approach of war to organize such an overpowering *moveable* force, as to be able to *strike* with effect at the vital points of the enemy, rather than to the construction of mere passive defences, therefore it is necessary to adopt that system of fortification which will give security to the dockyards, arsenals, &c., at the least possible expense, and with the least possible reduction of the moveable force; for an army when combined in the field can generally produce a far more decisive effect than when scattered in fortresses: at the same time, the works of defence should be arranged so as to enclose space enough to secure these dépôts from bombardment, and to cover large bodies of troops which may be temporarily incapable of taking the field.

To enable small garrisons to defend such extensive positions, they must be posted in strong works, placed, in general, between the salient points, provided with secure bomb-proofs for men and guns, adapted for an independent defence, and armed with powerful artillery, capable of being easily moved to the most advantageous positions for flanking the intervals between the works. In accordance with these principles, the accompanying Plan of a redoubt has been

left for the mines; or the wall between the piers may be entirely omitted, the earth being left at its natural slope.

The height of the caponières is such as to obstruct an enemy in breaching works at the rear along the line of the flank ditches, and being themselves very secure against breaching batteries, it would require mining to destroy them: the small casemates over them cover two guns each, commanding their capitals; they act as traverses or bonnets to the flanks, and the earth which covers them is formed into a parapet for marksmen to command the enemy's saps.

The hollow traverses over the magazines in the flanks can also contain two pieces, so that all the approaches are commanded by casemated guns.

The casemates of the envelope afford sufficient cover to its garrison, but are all seen into from the keep, so as to give no cover to an enemy.

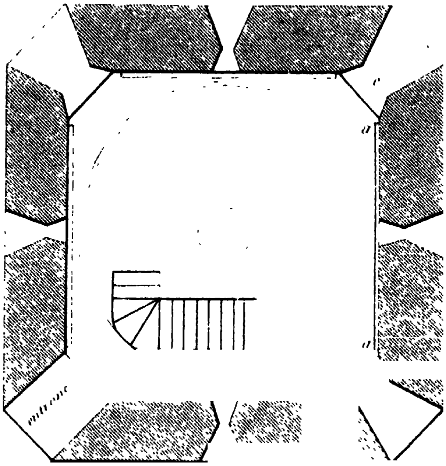
The keep is secured against assault by flanking loopholes, without requiring the aid of caponières for the defence of the front or rear, but the flanks or wings are defended by galleries in the gorge counterscarp, and by any works which may be situated in the rear: there is only one entrance into this work, and it is quite independent of its envelope (with which, however, its garrison might communicate by the large embrasures in front): over the entrance is an aperture in the arch for raising guns, &c., to the platform, which is covered by a casemate above, in which a gun may be placed; and the earth which covers it is formed into a parapet for musketry, so as to act as a cavalier: the mortar casemates have large embrasures, which may be partly or entirely closed by logs fitting into grooves at the sides, and any portion which may be breached can be easily cut off by retrenchments formed of timber, &c.: the embrasures should have gratings on hinges, and shutters for musketry defence.

The keep may be raised so as to obtain a direct fire on the glacis from the upper tier of casemates, if there is not space in front for an enemy to establish batteries capable of overpowering and breaching it when so uncovered.

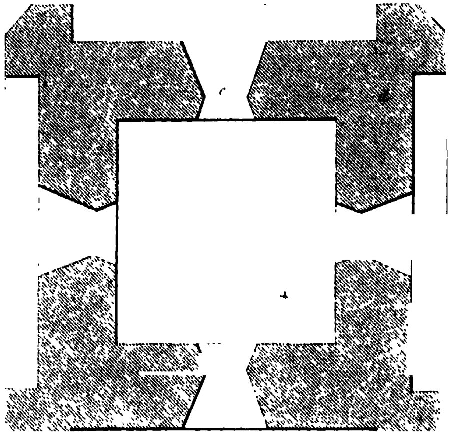
If the ditches can be flooded, the counterscarp wall and the lower floors of the caponières may be omitted; with a depth of 6 feet in the main ditch, that round the keep will be still dry. As the construction of the keep is simple and cheap, and its form is well adapted for a barrack or store even during peace, the cost of buildings required for those purposes in the fortress must be considered to be thus in part saved.

PROPOSED TOWER.

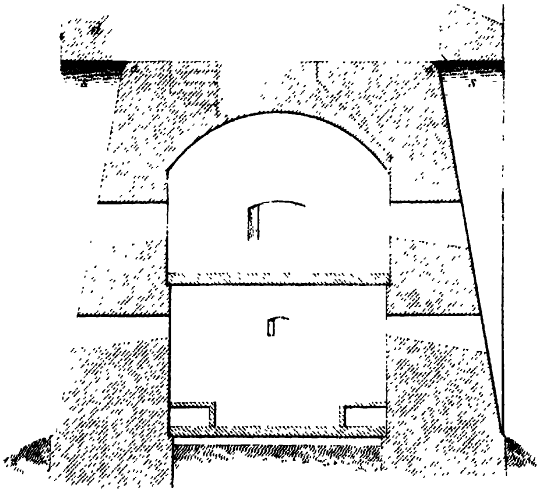
PLAN OF PLATFORM



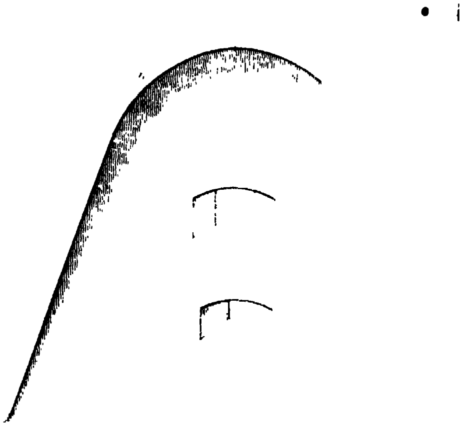
PLAN OF UPPER FLOOR



SECTION ON A B



ELEVATION OF EXTERIOR



a a Machicoulis loopholes
c c Embrasures for a howitzer or for musketry
N.B. a magazine & well may be constructed below

J. Le Keux sc.

London, John Weale, 59 High Holborn, 1847

PROPOSED TOWER.

To occupy confined sites, for the defence of passes or harbours, or as keeps to batteries and redoubts, Napoleon ordered that square towers should be adopted, as described in vol. iii. of the Royal Engineer Professional Papers, but the machicoulis defences of these works (consisting only in a small gallery at each side, covered by a wall merely 9 inches thick, resting on corbels) are evidently exposed to be quickly destroyed even by field artillery; and it is therefore proposed to substitute for them a parapet wall, 3 feet thick, resting on arches abutting on piers at the angles, as shown in Plan IV.; an interval of 4 inches between this and the main wall below it would form a long machicoulis loophole, and an enemy would be obliged to bring up heavy guns to destroy it, thus causing as much delay as can be expected from a tower. With such a weak machicoulis defence as that of the Napoleon Tower, a glacis appears to be superfluous, as the protection of the lower story against battering guns would be of little avail.

The arch of the proposed tower forms the cheapest possible bomb-proof covering, but one of iron or wood may generally be sufficient: its walls, although far less expensive, are of course not so strong as those of the Martello or Maximilian Towers, but it is better calculated than they are to resist an assault, as they have no machicoulis defence except over the door.

Its embrasures are so placed, that on every side two casemate guns and one howitzer on the platform can be brought to bear, besides the traversing gun in the centre of the latter: iron shutters and gratings may be provided for the embrasures, to adapt them for musketry defence and prevent surprise; the door also is placed on the level of the platform for greater security, but may be below, if more convenient access is required. By using hammocks, 50 men may be accommodated in it: a cellar may be excavated underneath, in which powder, provisions, and water may be placed.

P. J. Bainbrigge,

Cologne, April 2nd, 1845. Lieut. Royal Engineers.

IV.—*Draw-Bridges at Bermuda.*

Few officers of Engineers can have looked at the ordinary draw-bridges of fortifications without remarking that little change has been made in their construction during a period in which every other application of machinery has undergone very great improvement. The rolling bridge designed for Fort Regent, in Jersey,[1] by Mr. John Le Sueur, foreman of works at that station, and since adopted in two or three other places, and a suspension bridge invented by Colonel Blanshard, and applied at Bermuda, of which the defences were chiefly designed by him, appear to be the only exceptions to this remark: the draw-bridges generally seen are nearly the same as those used in feudal castles several centuries back.

To make the Corps acquainted with all the recent constructions would prove in this case, as in every other, an important step towards improvement; and the detailed drawings which have been forwarded to the Inspectors-General of Fortifications by Colonel Barry, the Commanding Engineer at Bermuda, render it easy to circulate the particulars of those which have been completed in the several new works at that station. Within the last five or six years, thirteen draw-bridges have been erected there, three of which are rolling bridges, and two on the suspension principle alluded to above. The others are of the usual construction, the principal differences between them being in the application of their counterpoises.

The following Table embraces the information transmitted from Bermuda, respecting the breadth of opening, the weight of the draw-bridge, the nature of the counterpoise, and the power and time required to remove the bridge in each case.

[1] Described in the fourth volume of these Papers.

No.	Nature of Bridge.	Weight.	Counterpoise.	Width of Opening.		To remove the Bridge.		Remarks.
						Men.	Time.	
		lbs.		Ft.	In.		Min.	
1	An ordinary lifting platform, 10 ft. in width.	Platform . . 2497 Counterpoise . 344	Two weights moving over pulleys.	9	0	4	2	The power is applied to handles on the outer edges of two wheels, 4 ft. in diameter, and on the same axis as the barrels, 5 inches in diameter, round which the chains of the bridge wind.
2	Do. Do.	Platform . . 2744 Counterpoise . 672	Do. Do.	10	0	6	1	The power applied by blocks and tackle, one end being fixed to arch of gateway, the other to the end of the platform. The time cannot include that necessary for fixing the tackle.
3	Do., but only 3 ft. in width.	Platform . . 224	None.	7	4	2	$\frac{1}{12}$	
4 5	Do., 9 ft. in width.	Platform . . 1288 Counterpoise . 448	Weights relieved in succession.	8	0	2	$\frac{1}{4}$	The power applied as in No. 1.
6	Do., 3 ft. 9 in. in width.	Platform . . 280	None.	8	10	4	$\frac{1}{4}$	
7	A falling platform, 7 ft. wide. (See Plate IX.)	(About) . . 1400	Continuation of the platform.	7	0	3	1	
8	Do., 5 ft. in width.	(About) . . 1200	Do.	9	0	—	$\frac{1}{20}$	A force of 2 lbs. and a period of 3 seconds are stated to be sufficient to trip the bridge, but it is not supposed the latter can include the time required to draw the bolts which are necessary with this construction.
9	Rolling, 9 ft. 6 in. in width.	4400	Do.	12	0	2	1	
10 11	Do., 3 ft. 6 in. in width.	1850	Do.	12	3	3	$\frac{1}{3}$	
12	Suspension, $3\frac{1}{2}$ ft. wide. (See Plate X.)	Pitch pine timber 900 Iron . . . 395 Total . . 1295	None.	42	0	2	3 or 4 to restore the bridge.	The opening is equal to the width of the ditch. The time required to restore the bridge depends upon the depth to which it is lowered. The time required to remove the bridge is not given.
13	Do., 2 ft. 6 in. wide.	Wood . . . 382 Iron . . . 232 Total . . 614	None.	20	0	2	—	

The following numbers, obtained by multiplying together the weight of the platform and the width of the opening, and dividing the product by the number of men required, and by the number of minutes during which they must be employed, afford a relative measure of the mechanical advantage of the arrangements of each of the first six bridges, so far as the raising of their platforms is concerned.

1	2809
2	4573
3	9858
4 and 5	20608
6	2473

Of these six bridges, the counterpoises applied to the fourth and fifth alone appear to require further notice. The advantage which these two bridges seem to possess over the other four with lifting platforms may be attributed to the peculiar arrangement of their counterpoises, which permits them to be made much heavier, and more nearly equal to the platform, without inconvenience.

The counterpoises of these bridges are composed of a succession of cylindrical leaden weights, of 7 or 8 lbs. each, formed into a chain by iron side-pieces connected by iron pins passing through the weights, as shown in the Plate. One end of this chain of weights is attached to the chain by which the bridge is raised; the other to a pin fixed in the well in which the counterpoise works, and on a level with the under side of the lowest weight when the bridge is down. As the bridge is raised, and the angle by which the chain acts upon it becomes less acute, and a less power consequently is required to balance it, the weights in succession become suspended from the above-mentioned pin, and cease to act as parts of the counterpoise. In the fifth volume of the Professional Papers a similar counterpoise has been mentioned by Lieutenant Galton, R.E., in his Paper on Draw-bridges, as the invention of M. de Poncelet.

If it be supposed that the two suspending chains are fastened to the extremity of the platform as they generally are, and that each is attached to a counterpoise, the whole weight of each counterpoise to balance the bridge should be about one-third of the weight of the platform.

When the platform is at its lowest position, the whole of both counterpoises will be required to balance it; when at its highest, no counterpoise should be required, if the axis be in the middle of the thickness of the bridge: the length of each chain of weights, therefore, should be equal to the length of the chord

of the arc through which the end of the bridge (or other part to which the suspending chains are attached) moves.

And since in every position of the bridge, the triangle, which in a side elevation would be formed by the upper line of the platform, the face of the gateway (if upright), and the suspending chain, represents the forces in action,—and the two last-named sides represent respectively the half weight of the platform and the weight of the counterpoise required, the former of which is constant,—it is evident that the counterpoise ought to diminish as the bridge rises, in the same proportion as the chord of the arc, or length of the suspending chain; and this must be the case if all the links of the counterpoises are equal to each other.

In the bridges at Bermuda the last conditions have been observed, the counterpoises are composed of equal weights throughout, and the length of each counterpoise is equal to the chord of the arc through which the end of the bridge is raised. But the whole weight of the counterpoise is not more than half of that which would be required to balance the platform when horizontal, and it is possible that this is a good arrangement; for since some men must be employed to work the bridge, it may be advantageous to leave a part of the weight to be overcome by their exertion when raising it, and to act in their favour when lowering it. And as a general rule, perhaps, with this view of the subject, the counterpoise might be less than the weight necessary to balance the bridge by the estimated power of two men, first diminished by the proportion requisite to overcome the friction of the machinery, and then reduced from the point at which they act to the point where the counterpoise is applied; but it must be remembered, that if perfectly balanced, the intermediate machinery required to give a mechanical advantage to the men employed might be dispensed with.

The advantage of the counterpoise just described does not merely consist in enabling a bridge to be more rapidly raised: since the platform is balanced in the same proportion in all positions, it is more generally manageable, and can be lowered without difficulty; whereas the invariable counterpoises of Nos. 1 and 2 must oppose a resistance to the lowering of a bridge; and for this reason, when the bridge is heavy, it may be considered impossible to apply an efficient counterpoise of that description.

There are some advantages attending the principle on which the seventh and eighth bridges are constructed; the withdrawal of the bolts insures the fall of

the platform, and there are no chains exposed to injury. The two parts of the platform, also moving through similar arcs, balance each other in an equal degree in all positions, if the axis be properly placed. The bolts, however, are exposed to a severe strain, and if bent by it, may become difficult to draw. It is evidently inapplicable to a wide opening. The plans of No. 7 include the details of the cast iron-work employed for the standing part, which may be useful.

The detailed description of the rolling bridge at Fort Regent, which has been given in the fourth volume of the Professional Papers, renders a very brief notice of the bridges numbered 9, 10, and 11, in the foregoing Table, sufficient. Neither of these leaves, when removed, so wide an opening by nearly 5 feet as that at Jersey; and Nos. 10 and 11 are only foot-bridges. No. 9 presents the following difference in detail from that at Fort Regent: instead of being worked by a pinion on the windlass axle, acting on a toothed bar along the centre of the under side of the platform, it is worked by two chains, one on each side, each of which, being fixed to the masonry under the bridge, near the front of the opening in the escarp, and passing thence round a sheave attached to the inner extremity of the platform, makes one turn round the windlass, from thence passes round a sheave near the outer extremity of the platform, and, finally, is fastened at another point in the masonry beneath the bridge, and within the opening through the escarp. The mechanical advantage thus given to the men working the bridge is that occasioned by the difference between the diameter of the windlass wheel and the diameter of its barrel, and by a moveable pulley in whichsoever direction they are moving it.

In comparing these bridges with those compared together above, only half the weight of the platform must be considered to be moved, as rather more than half is merely counterpoise. The numbers representing their relative mechanical advantages will be,—

For No. 9	13200,
For Nos. 10 and 11	11339,

which numbers appear to show that the mechanical advantages of the arrangements of these bridges are less than those of Nos. 4 and 5, although they are completely counterpoised, which the latter are not.

With rolling bridges, as they have been constructed, the principal resistance to be overcome is the friction on the axles of the rollers, being a certain propor-

tion of the weight of the bridge: in other bridges, with lifting, or falling platforms having perfect counterpoises, the principal resistance to motion is the friction on the axle of the bridge, or on the axles of the levers or pulleys by which the weight is borne, which will generally be a similar proportion of the weight of the bridge. The resistance produced by this friction is diminished as the diameters of the rollers of the former, or of the pulleys of the latter, are increased, within, of course, such limits that the weight of these rollers or pulleys may not create an additional friction equal to the diminution effected by their increased diameters. The rollers used at Fort Regent and at Bermuda appear to be much too small; and when it is considered that an unloaded railway carriage truck is heavier than the largest of the Bermudian rolling bridges, and that one man can easily move such a truck on a level railway through a greater space than 12 feet in a minute, it cannot be doubted that the present arrangements of our rolling bridges are imperfect, nor that they might be applied on a larger scale than they have hitherto been, without requiring any assistance from windlasses or pulleys. It may also be observed, that when employed with fixed trucks, as at present, on so large a scale that some mechanical advantage must be given to the men, their power might be so applied as to produce motion in that pair of wheels, or trucks, on which the chief weight of the bridge is supported, and without the addition of either a racked bar or a chain. And further, that it appears very probable this description of bridge may enable the friction on the axles of levers, or pulleys, to be entirely avoided, instead of being merely transferred to trucks; since the trucks might be attached to a frame working independently between the bridge and the floor of the passage or gateway into which the bridge runs.

Nos. 12 and 13, the two suspension bridges, alone remain to be noticed. Their conception and design are due to Colonel Blanshard, and it is believed that they are the only examples of the application of the principles of suspension bridges to draw-bridges.

In No. 12, the bridge is carried by four iron chains, two on each side; of the two chains on the same side, one is 2 ft. 8 in. immediately above the other; each of the two upper chains is securely fastened to the ground about 12 feet beyond the counterscarp, and after passing over a pillar at a height of about two feet, and at a distance of one foot from the edge of the counterscarp, crosses the ditch, of which the width is 42 feet, passes over a 6-inch sheave on the side of the opening through the escarp at the same level as the top of the pillar

beyond the counterscarp, and thence round a windlass beneath the roadway, about 23 feet in rear of the face of the escarp. The drop of the chain, when the platform of the bridge is horizontal, is 3 feet.

The lower chain on each side is securely fastened to a hook in the face of the counterscarp, and after crossing the ditch, passes over a sheave similar, and similarly fixed, to that for the upper chain, but 2 ft. 8 in. below it, and round a similar windlass, similarly placed below the road-way, but 3 feet nearer to the escarp. The drop of this chain when the platform is horizontal is also 3 feet. The distance between the two pairs of chains, or the width of the road-way, is 3 ft. 6 in.

From the chains are pendent twelve suspending-pieces, six on each side, dividing equally the interval between the escarp and counterscarp; these vary in length to suit the several intervals between the lower chain and the platform, but the distance between the two points of connection with the two chains is 2 ft. 8 in. in each bar. It may be seen from the Plate that the chains pass through the bars.

The lower ends of each pair of opposite suspending rods pass through a horizontal cross-piece of pitch pine, 4 feet long, and 3 in. by 4 in. in section. Each pair of opposite suspending-pieces form with their cross-piece a stirrup to carry the platform.

The platform is composed of three rows of pitch pine joists, 3 in. by 4 in., covered with 1¼-inch pitch pine planks. The joists of the two outside rows overlap each other by about a foot, and each two that are thus in contact are connected together by a 2-inch iron pin passing through iron eyes on the upper surface of the joists. Of two joists in contact, that which is nearest lies within that which is furthest from the counterscarp, so that these outer joists present an arrangement similar to that of the side-pieces of several lengths of scaling ladders when put together, or to that which Colonel Blanshard has adopted for the cleats to the chasses of his pontoon bridge. One of the two eyes, fixed on each outer joist for the connecting pins to pass through, being close to that end which is next to the counterscarp, and both these eyes being on the upper surface, the overlapping part of the joist which extends beyond the pin moves away from the planking when the bridge collapses in lowering. The three joists next the counterscarp are connected with it by hinges on their under side. One plank in each bay, that which is above the meetings of the joists and the cross-piece supporting them, is not nailed to the joists, but secured by

hinges on its upper side to the plank next it towards the counterscarp, and being bevelled on the other edge, the planking presents no impediment to the bending of the bridge as it is lowered. That bay of the platform which is next to the escarp is not permanently connected with the remainder, but is a trap similar to those of the foot-bridges, Nos. 3 and 6. The drawings do not show the mode of connecting this lifting bay with the part dependent on the chains when the bridge is raised and in use, but the necessity for their secure connection is obvious, and an arrangement for the purpose may be easily conceived.

As there is no counterpoise, the bridge must fall on the windlasses being released; and as it falls the several suspending-pieces retain nearly their vertical position, the chains by which each is connected with either the escarp, or counterscarp, or adjacent suspending-piece, being nearly equal and parallel; but the cross-pieces slip along the under side of the platform towards the counterscarp, their several distances from the hinges by which the platform is attached to the counterscarp, and on which it turns, being diminished as they fall: this motion is greatest with the two centre suspending-pieces, and would amount with them to nearly 3 feet if completely lowered. When the bridge is raised, each suspending-piece, being acted upon by two chains, is brought to its proper position under the joists, and from the arrangement of the latter there is no danger of any catch or impediment.

Without the aid of any counterpoise, this bridge can be raised by two men in four minutes, the weight of the platform being 1295 lbs., and the width of the opening 42 feet. Adopting these figures, the number by which its mechanical efficiency, in comparison with the other bridges, may be expressed, is 6798. But the weight returned evidently does not include the weight of the chains, 168 feet of which ought to be included, as the four lengths across the ditch are not merely lifting chains, but the supports of the bridge. Assuming the weight with the chains to be 1900 lbs., the comparative number will be 9975.

No. 13 being adapted only for an opening of 20 feet, has only one joint in the suspended part of the platform, besides that connecting it with the counterscarp, and only one chain on each side is employed: the suspending-pieces are connected with iron instead of wooden cross-pieces, which do not slide along the under side of the platform.

It appears reasonable to suppose that the suggestion of the principle of suspension, of which the first application is here described, may produce much improvement in draw-bridges. The advantages attending the above con-

struction are, the greater opening afforded, and the abolition of the obstruction caused by the standing part. It is impossible for an enemy to prevent the removal of the bridge; and provided four chains are employed, it does not appear to be much more liable to such injury as would render it unserviceable until a tedious repair had been completed than other draw-bridges.

The example before us is most probably deficient in stiffness, and there does not appear to be any sufficient reason for the frequent subdivision of the platform, by which its extreme flexibility is produced. The first joint next the counterscarp might be equal in length to the height of the bridge above the bottom of the ditch; and it is not difficult to conceive that an arrangement might be adopted by which the whole bridge should be composed of two leaves, one to lie against the escarp, the other against the counterscarp when lowered. The greatest defect of suspension bridges is their flexibility, for it is quite impossible to calculate with certainty on the proper proportions for parts exposed to much vibration while heavily loaded, and it is necessary therefore to do every thing that can be done to give them stability. For the narrow openings of the ditches of fortifications, it need not be difficult to obtain considerable stability: the platform may be composed of two well-braced leaves, as mentioned above, and, when the bridge is required as an ordinary communication, their junction may be stiffened by two side-pieces, and the whole strengthened by a second course of planking laid longitudinally: the suspending-pieces of the leaf next the counterscarp may be fastened to the chains, as in the present example, and those of the leaf next the escarp jointed to the sides of that leaf, the chains being allowed to run through them. A counterpoise, bearing a considerable proportion to the tension of the chain when the bridge is raised, might be employed to facilitate the raising, and relieve the strain upon the windlasses, their pivots and stops, which, with the arrangement described above, must be very great when the bridge is loaded; and to accommodate the action of the counterpoise to the position of the bridge, it might be formed as a roller running on a curve, of which the inclination, when the bridge is down, should be just sufficient to cause the weight of the counterpoise to balance its friction and the extra length of the chains, probably about 5°; and when the bridge is up, the counterpoise should hang freely, exerting its whole weight.

The whole weight of the moveable part of such a bridge, 60 feet in length and 10 feet in width, need not be very great: there does not appear to be any thing unreasonable in anticipating its construction.

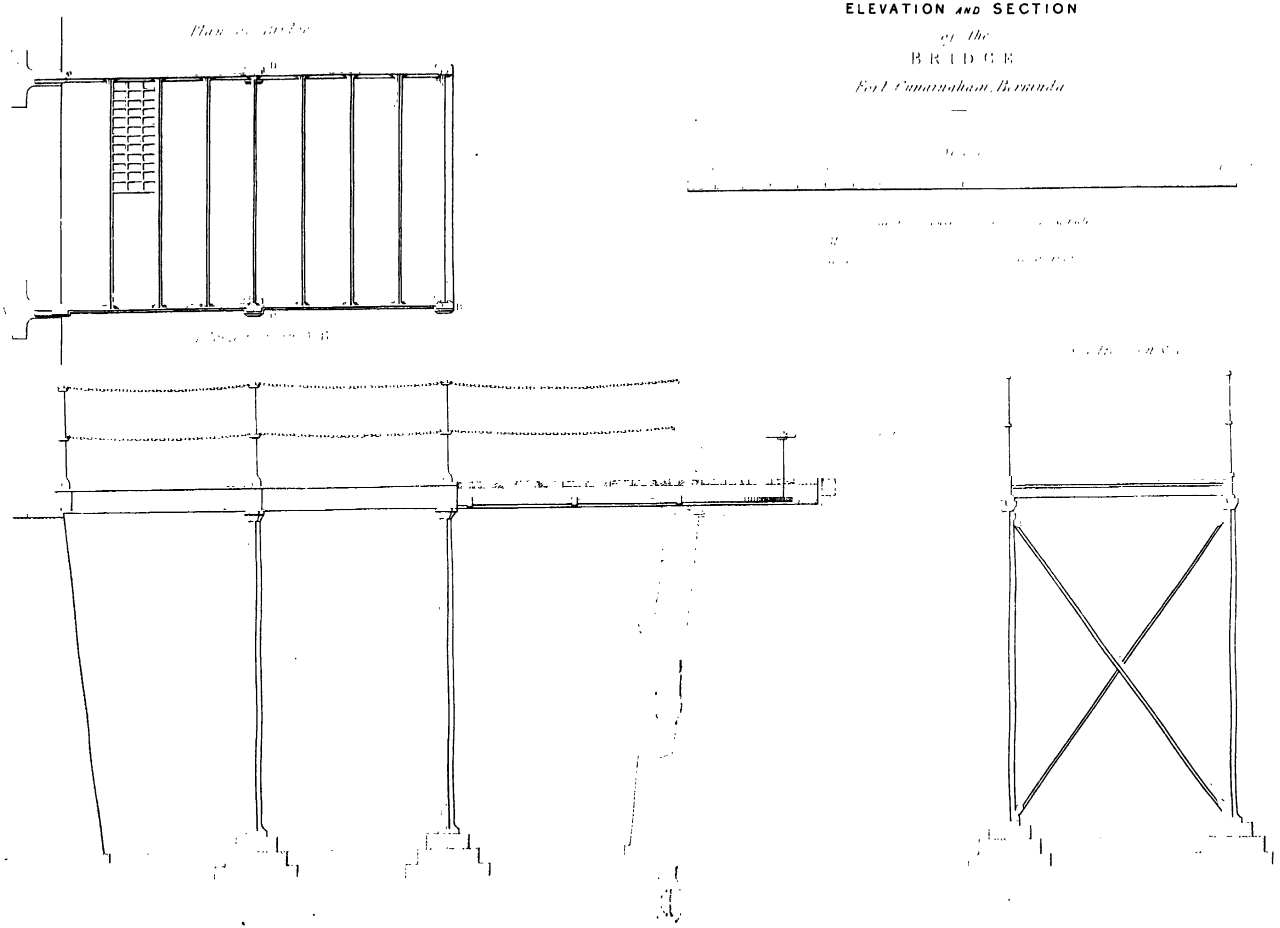
PLAN

ELEVATION AND SECTION

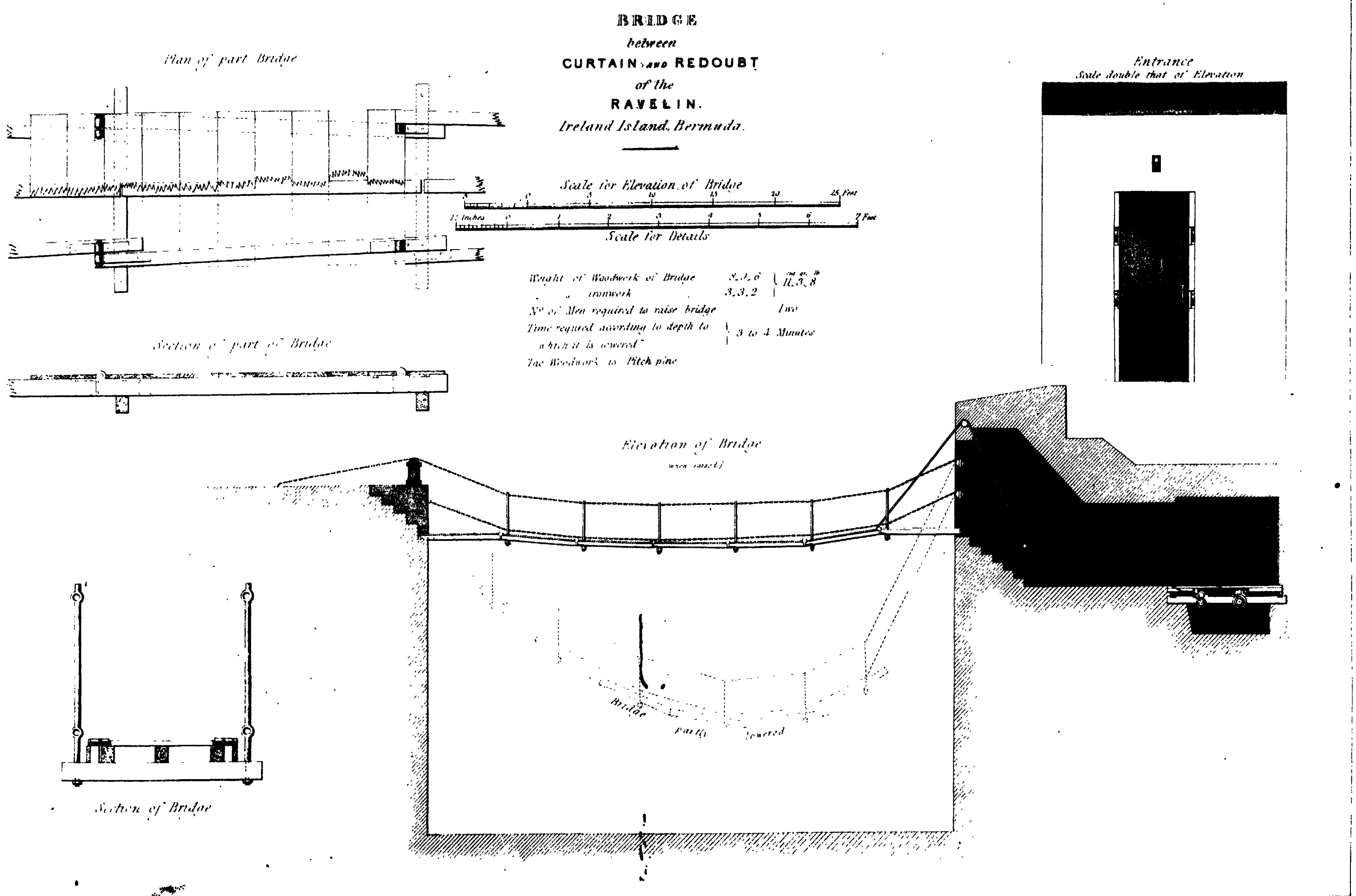
of the

BRIDGE

Fort Cunningham, Bermuda



BRIDGE between CURTAIN and REDOUBT of the RAVELIN. Ireland Island, Bermuda.



F. A. Bernays del.
London, John Weale, 1845
Hawksworth sc.

It would be necessary, in arranging its proportions, to provide for an equally distributed weight of about 40 tons, or 10 tons on each chain. The chains could generally be raised to a height of 6 or 7 feet above the covered-way without exposure; one on each side could be carried to the under side of the platform, and the vertical interval between those on the same side, to reduce the chance of their being both injured by one shot as much as possible, need not exceed 1 ft. 6 in.: the drop, or deflection of each chain, then may be 6 feet, or one-tenth of the span, and each chain would require to be proved to a tension of 13½ tons. The chains then should be made of good 1-inch iron, or it would be preferable to adopt 3¾-inch iron rope,

	lbs.
The weight of 247 feet of which (allowing for the four ropes) would be about	680
22 suspension rods, 11 on each side, made of ¾-inch round iron . .	120
11 wrought iron cross-pieces, upper flange 2 inches by 0·6 inch; lower ditto 2 inches by 0·6; middle ribs 3·3 inches by 0·6, or total depth of 4½ inches iron	1650
660 running feet pitch pine joists, 2 inches by 5 inches . . . and 600 superficial feet do., 1½-inch planking	5950
Total weight	8400 lbs.

or a little less than 3¾ tons, for which two weights of 2½ tons each would be a complete counterpoise.

V.—*Description of Wrought Iron Roofs erected over two Building Slips in the Royal Dockyard at Pembroke, South Wales. By Capt.* WILLIAMS, *R.E.*

THE covering of building slips in our Royal Dockyards with permanent roofs is of comparatively recent practice.

At Venice,[1] roofs to both docks and slips have been used from time immemorial: the French, Swedes, and Dutch also adopted them many years ago, but it was not until the British public had undergone almost a panic, from the alarming prevalence, towards the latter part of the last protracted war, of dry-rot in the fleets, that their value and importance were appreciated. The first permanent slip roof was erected in Plymouth Dockyard in 1814, since which they have become universal in the Royal Dockyards, although still unknown in private ship-building establishments.

It is a rule, that ships shall remain at least two years in frame under these roofs, before they are finally planked in and completed; so that should the timbers have been imperfectly seasoned before they are put together, they have still the important benefit of protection from weather, with perfect freedom of ventilation, during that period. It is obvious, that ships built under such circumstances must be infinitely superior to those which throughout their construction have been more or less exposed to be soaked, swelled, shrunk, or rifted at every change of season; and that the economy, as well as efficiency, of the Naval Service is promoted by the work of the shipwrights being never interrupted or suspended by the weather.

The earlier roofs were of the ordinary shed-like form externally: they were much enlarged and improved upon by the late Sir Robert Seppings; and our

[1] In a work published in 1821 by Mr. John Knowles, called 'An Inquiry into the Means which have been taken to preserve the British Navy,' it is stated that in the year 1790 there were 22 ships of the line under roofs at this port, some of which had been in that situation 59 years.

dockyards now present stupendous sheds constructed on his plan, displaying an ingenious system of trussing, and a handsome and imposing form.

Plate XI. is a section of one of these roofs; it is erected over No. 3 slip (calculated for a first-rate) in Pembroke Dockyard; its span is 100 feet, and extreme width from eave to eave 160 feet: the entire area of ground covered is 291′ 3″ × 160′ 0″. It has twenty-four standards, 11′ 9″ apart from centre to centre, in each of the two parallel rows, and eight at the hipped end; and the height from the ground line at the two fore standards to the apex is 60′ 7″. It is covered with zinc, and was erected in 1841 at a cost of £7500.

Hitherto the slip roofs have been all made of timber, with coverings of sheet iron, sheet copper, zinc, slates, tarred paper, or canvass: creditable achievements in carpentry, but presenting masses of inflammable material which prudence suggests the expediency of replacing, as opportunity offers, by constructions free from so fatal an objection.

The roofs over the adjoining slips, Nos. 8 and 9, in Pembroke yard being totally decayed, Captain Brandreth, R.E., Director-General of Works to the Admiralty, recommended that they should be replaced by iron ones.

A considerable degree of enterprise and mechanical skill was required to carry out with reasonable economy this sound measure; for no iron roof hitherto constructed equalled what was now called for, either in magnitude or difficulty of combination, to meet the conditions peculiar to slip roofs.

Several designs were proposed; but that of Messrs. Fox, Henderson, and Co., of the London Iron Works, Birmingham, having met with approval, they entered into a contract to put up the two roofs for the sum of £15,480, taking the responsibility of stability upon themselves: they were commenced in September, 1844, under the immediate superintendence of their Resident Engineer, Mr. J. Hughes.

The slips over which they are erected are each 262 feet long, and 58 feet wide: they are not exactly parallel to each other, their central longitudinal lines diverging nearly 3 feet at their upper end. Their side-wall copings have a fall of 10 feet in their whole length.

The ingenious application of bar and angle iron throughout the entire framework, combining the leading obligations of lightness and strength, is a peculiar feature in the construction of these roofs: no bar exceeds 4″ × ½″, yet by the judicious combination of materials of such slight dimensions, all the strength required to resist the immense strains to which roofs of such magnitude are

exposed in a place subject to most violent gales, has been most successfully obtained.

Plates XII. XIII. and XIV. exhibit their form and principle; but a brief account of the order pursued in their erection, and of the mode of connecting the principal parts, may not be deemed superfluous; and as the two roofs are exactly alike, except as regards their angles on plan, a description of one will apply to both.

The parallel part of the roof is supported by two rows, 80′ 7⅝″ apart, of cast iron standards, twenty-one in each row; and the polygonal part by six more, making forty-eight in all: their central distances in the rows are 12′ 6⅜″; but in the ends, these are determined by dividing the semi-circumference of a circle, whose radius is half the span of the roof, into nine parts. In order, however, to obtain two wide road-ways to the slips, one standard next to each fore standard is omitted; and the spaces are arched over by two massive cast iron girders, each weighing 7 tons, and carrying at their crowns, which are made to fall in the line of circumference, a semi-standard, on the top of which a hip rafter abuts, by which means the regular division of the polygonal roof into nine similar triangular parcels is not disturbed.

All the whole standards are of an equal length, 42′ 8″, and of the double flanche form; they are 1 inch thick, weighing about 3 tons each: figs. 13, Plate XV., show their form and section, and their positions are shown in Plate XII.: those marked *a*, *a*, *a*, *a*, having each to sustain an extra 3½ tons, were strengthened below the heavy girders by two additional cast iron pilasters, 1½ inch thick, inserted between the flanches, and bolted to the web.

For the support of every standard, a rubble masonry pier, 6 feet square, was carried up from the natural rock, to within 9′ 6″ of the ground line; on this a shaft is built, at the bottom of which a step-stone of granite, 4 feet square, and 2 feet thick, is firmly bedded: the toe of the standard is received into a mortise 6 inches deep, cut in the granite, and is therefore 8 feet below the ground line; the shafts are terminated by granite copings, 2 feet thick, set in cement, and firmly embracing the standards.

The heads of the standards are connected by cast iron girders, (fig. 9, Plate XV.,) weighing about 6 cwt., secured at either end by two 1-inch double screw-bolts passing through the web of the standard and the corresponding end of the adjoining girder, and thus forming a continuous tie from end to end of the roof. At the polygonal end these girders are somewhat longer, and their

ends are bevelled to meet the oblique position of the standards they abut upon.

The side and overhanging roofs (*b*, *c*, R, and *c*, *e*, R,) consist of two assemblages of struts and ties, put together on the ground in two separate parts, previously to being fixed to the standards: Plates XIV. XV. show their position and details. The principal feature of these is the main strut or gib, the form of which is suited to resist very powerful thrusts and strains: each of its two sides consists of two bars of angle iron, $4'' \times \frac{1}{2}''$, wrought into the bowed figure represented in fig. 11, Plate XV., and fastened together with red-hot rivets; their ends embrace, and are bolted to the tenons of a cast iron shoe and head, (figs. 10 and 12, Plate XV.) The distance-pieces are of cast iron, secured by their side plates to the angle iron, by red-hot rivets: the weights of the head and shoe are respectively 148 lbs. and 202 lbs.; of the largest distance-pieces 111 lbs.; and of the entire strut about 1 ton.

The tie-bar (B), Plate XIV., connecting the head of the gib with that of the standard, forms the rafter of the side roof, and consists of two flitches, each $4'' \times \frac{1}{2}''$, with cast iron distance-pieces 1 foot apart, (see fig. 8, Pl. XIV.) The forked struts (N N, figs. 12) are of $2\frac{1}{2}'' \times \frac{5}{16}''$ iron, with cast distance-pieces; their upper ends are received between and bolted to the flitches of the rafter; the lower ends are secured to cast iron shoes (fig. 5), which are bolted to the flanche of the gib. A forked tie-rod of 1″ iron, bolted at top to the rafter near the head of the standard, and below to the flanche of the gib, completes this assemblage.

The eave or overhanging roof consists of a truss (*c e* T, Pl. XIV.) suspended from the head of the standard, and maintained at its proper angle of projection by the forked strut (L, fig. 6, Plate XV.); a cast iron box (fig. 4, Plate XIV.), having two bolt-holes (*a a*), is attached at R, to the standard, by two T-headed bolts with nuts, which pass through the box and the flanche of the standard: each pair of flitches at the open end of the struts embraces and is bolted to the T-head (*b*, fig. 4). The closed end is received along with the foot of the strut (K) and tie (I) into a boss or shoe (T), cast in two pieces, and is fastened to it by a central screw-bolt: the shoe is shown in figs. 3, Plate XIV.: the feet of the struts (M M) are also received into the same shoe, and are bolted to it at *b b*: the opposite ends of I, K, M M are bolted between the flitches of the rafter, which is of the same construction as the rafter B.

In order to render the point (T) quite immoveable, it is further attached to the standard by a tie-rod (U) of 1-inch iron.

A truss of 92′ 4″ span extends from head to head of opposite and corresponding main struts or gibs: the tie-bar consists of two flitches without distance-pieces; those of the outward portions (D, Plate XIV.) are of $4'' \times \frac{1}{2}''$ iron, and of the central portion (E) $4'' \times \frac{5}{16}''$ iron; their ends at S overlap, and, as well as those of the ties F and G, are secured by the central bolt of the boss or shoe (S), which, like that at T, is cast in two pieces. The struts at *o o*, abutting on the shoe, are secured by bolts at *b b*, fig. 2: their heads are bolted between the flitches of the rafters.

Figs. 13 show the details of the king-head: a socket is cast on it, into the lower part of which the head of the king-rod is received, and secured by a colter; the upper part of the socket is occupied by a bolt similarly secured: this bolt passes through the joint plate of the ridge-piece, and, having a nut at top, fastens it firmly down on the roof.

The flitches of the two rafters clasp the longer arms of the casting, and are bolted to it; those of the ridge purlin are similarly attached to the short arms (*b b*).

The foot of the king-rod is secured to the tie-bar by a casting (fig. 10), bolted between the flitches; the tie-rod passes through it, and is adjusted in its length by a nut underneath.

The purlins are not all of similar construction; those at *a* and *b*, Pl. XIV., consist of angle iron trussed (fig. 8, Plate XV.); those at *i*, *k*, *l*, *m*, *c*, *w*, *o*, Pl. XIV., of flat bars trussed (fig. 7, Pl. XV.); and those at *e*, Pl. XIV., of flat bars, $3'' \times \frac{5}{16}''$, not trussed: they all have cast iron distance-pieces riveted to them by red-hot rivets, and perforated to receive the bolts by which the corrugated iron covering is fastened down. The extremities of the purlins are bolted to cast iron shoes (fig. 5, Pl. XV.), which again are bolted to the rafters, the same bolt also securing the diagonal ties which spread an iron net over the entire roof (see Plate XIII.): these ties consist of flat bars on edge, of $2\frac{1}{2}'' \times \frac{5}{16}''$ iron, and are adjustible in their lengths by a gib and key in the centre of each.

A continuous tie (F, G, H, Plate XIV.) connects the ridge with the head of the standard, by one truss as it were, having a king-rod at *b*: at V one of the distance-pieces of the main strut becomes a cross head (A, fig. 11, Plate XV.), which the bar passes through.

The rafters of the polygonal end of the roof radiate from a cast iron crown-piece or king-head (fig. 2, Plate XV.), bolted at *a* to the ridge purlin; a notch, cut on their under side, fits on to the projection *b*, and they are kept from rising by two circular straps bolted down through the bolt-holes shown in the figure: these rafters, as well as the purlins and struts, differ somewhat in scantling and length with the corresponding parts of the parallel roof, but the construction is similar.

The heads of the standards of the polygon have the additional security of a continuous tie of 2-inch wrought round iron, bolted to them immediately above the arched girders, which latter, being of cast iron, might be inadequate to resist oblique strains, and the pressure of the massive girders over the roadways: these ponderous masses of iron, being too large and of an inconvenient form to cast in one piece, were divided into two, meeting at the crown of the arch, where they are secured by powerful joggles: in plan they are salient at the centre, in order to bring the semi-standard they carry there into the line of the circumference of the polygon.

The corrugated iron of which the covering of the roof is composed is No. 17, Birmingham wire guage, weighing about $2\frac{1}{2}$ lbs. to the foot; the sheets are $2' \; 2\frac{3}{4}''$ wide, containing six corrugations: their usual length is 7 feet, but they are cut to suit what may be required; they are laid with a top lap of $4\frac{1}{2}''$, riveted with two rows, $2\frac{1}{2}''$ apart, of $\frac{1}{2}'' \times \frac{3}{16}''$ rivets, $4\frac{1}{4}''$ from each other, and with a side lap of $1\frac{1}{4}''$, fastened by one row of rivets $8\frac{1}{2}''$ asunder. They are secured to the purlins by $\frac{3}{8}''$ bolts, which pass through the distance-pieces, and are tightened by nuts on the under side.

The ridge of the ordinary roof, and the joints of the panels of the hips, have cast iron ridge-pieces or copings, $\frac{5}{16}''$ thick, which are bolted to the principals: the sides or curtains of these copings are scolloped to fit the corrugations of the covering iron: the castings are in lengths of about $6\frac{1}{4}$ feet, screwed to each other through flanches on the under side.

The exterior gutters (fig. 1, Plate XV.) are supported by triangular cast iron brackets, bolted to the extremities of the rafters at *a*: the knob at *b*, projecting a little under the lower edge of the rafter, prevents the weight of the gutter, which is $1\frac{1}{8}''$ thick, from turning on *a* as a pivot. An ornamental facia plate is bolted to the exterior face.

The interior gutter is common to both roofs, and is carried by wrought iron girths, bolted to the extremities of the rafters of the interior side roofs.

There are 123 sky-lights, $5' \, 3'' \times 5' \, 0''$, fixed in the roof: the frames are of cast iron, and are bolted to the corrugated covering, in which openings were cut to receive them.

The simplicity of the means applied in the erection of these roofs is not the least interesting consideration connected with them. The slips which they cover were the workshops, temporary lean-to sheds being made with a few sheets of corrugated iron, supported by light spars, under the protection of which all the fire-work was carried on with three or four portable forges, spaces being reserved for stowage of the numerous small castings, rivets, bolts; &c. In so complicated and novel a work, it was not to be expected that the extreme niceties required in the adjustments of the various parts could be overcome without much fitting on the spot. The slips therefore became a scene of active operations, without in the slightest degree interfering with the works of the shipwrights in the adjoining slips.

A brief notice of the order followed, and of the skilful means adopted, in the erection of these roofs, will complete this Paper.

The fixing of the standards was the first operation. To hoist these, a common spar, about 59 feet long, and 1 foot square (having a cross-piece at its head, to which a 10-inch triple block was made fast), was stepped into a wooden shoe, $5\frac{1}{2}$ feet long, 8 inches thick, and 2 feet broad; four or five guy-ropes being attached, it became a derrick: with the assistance of blocks and tackle applied at the base, and with any convenient purchase at hand, three men hauling on the rope, and one man pushing behind with a handspike, were sufficient to move it from point to point, rollers being previously placed under it, and a couple of planks laid down for them to run upon. A 10-inch double block, with a shackle, was suspended with proper tackle to the block at the head: the standard was attached to the shackle by a chain, and the rope (which after passing twice through both blocks is brought down to a 9-inch snatch block, made fast to the foot of the derrick,) being led to a double-purchase crab capstan, worked by five men, the standard was lifted up, and let down into its berth without difficulty. At the commencement of the operations but three standards could be fixed in one day; but experience gave the workmen so much skill, that nine were finally fixed in the same period.

These simple derricks, of which five only were used; an occasional stage, consisting of a few planks supported by portions of the roof itself; a trestle, made by connecting a few bars of angle iron; three or four common ladders;

a wooden seat, on which a workman was hoisted by a rope and pulley, and three crab capstans, constituted the principal machinery employed in putting all the parts of the roofs together.

The levels of the standard pits had been regulated with as much nicety as masons' work is susceptible of: it was, however, found necessary to make some adjustments to bring the standards into an exact plane, by interposing small plates of iron of the required thicknesses between them and the granite step-stones.[2] The standards were then plumbed; and small blocks of wood being bolted to them at about two-thirds of their height, each was shored up, and kept in its true position by four planks. The arched girders connecting their heads were then bolted to them.

The overhanging roof, previously put together on the ground, was then hoisted and bolted to the outer side of the standard; then followed the side roof, attached below by its shoe to the opposite side of the standard by four bolts passing through slots into the flanches: the heel of the shoe derives further support from a small projecting step cast on the standard.

Similar operations are carried on at the opposite corresponding standards, until five or six pairs have been thus far completed, when they are connected and steadied by the application, first of the upper and lower purlins, and afterwards by that of the intermediate ones.

They are then ready to receive the crowning truss, which, strengthened by a plank or two, to prevent its buckling with its own weight while in the false position of suspension, is hoisted into its berth. This required a derrick 70 feet high, and there being no spars long enough, additional length was obtained by bolting a plank on two opposite sides of the upper end of the spar, connected above that by iron cross-pieces or bolts: this was the longest derrick required.

The lighter portions of framing were hoisted by a derrick made with a common scaffold pole; while still smaller pieces, and occasionally even the workmen, were raised by a simple rope and pulley, fixed as convenience required to any of the framing already in position. The activity and courage

[2] This was attended with some inconvenience and loss of time, and in future cases I should recommend that the standard pits should not be carried up beyond the granite step-stone until the standards have been erected. This course was intended to have been pursued, but was over-ruled by the Dockyard authorities, on account of the inconvenience that would arise from the ground being left open, with materials lying about, during the interval between building the slips and the erection of the roofs.

of the workmen were the subject of general admiration; a ladder, or a single plank, or more generally the naked framing itself, supporting them at their aerial tasks, which were not discontinued excepting in very severe weather.

The remaining purlins and the wind-ties being fixed, the corrugated iron, previously riveted together in pieces of four or more sheets, was applied. The further riveting of these together was, of course, done on the roof, by men working in pairs, one man outside, the other with a dolly underneath the holes were also punched from the top, and the bolts inserted through the covering and purlin distance-pieces, the man beneath screwing all firmly together by the nuts. All the rivets and bolts are applied at the ridges of the corrugations, by which means the wet is effectually excluded.

The openings for the sky-lights were cut out with chisels: this process was adopted with a view to greater accuracy of position than could have been obtained by fixing the lights in the corrugated iron before it was put up.

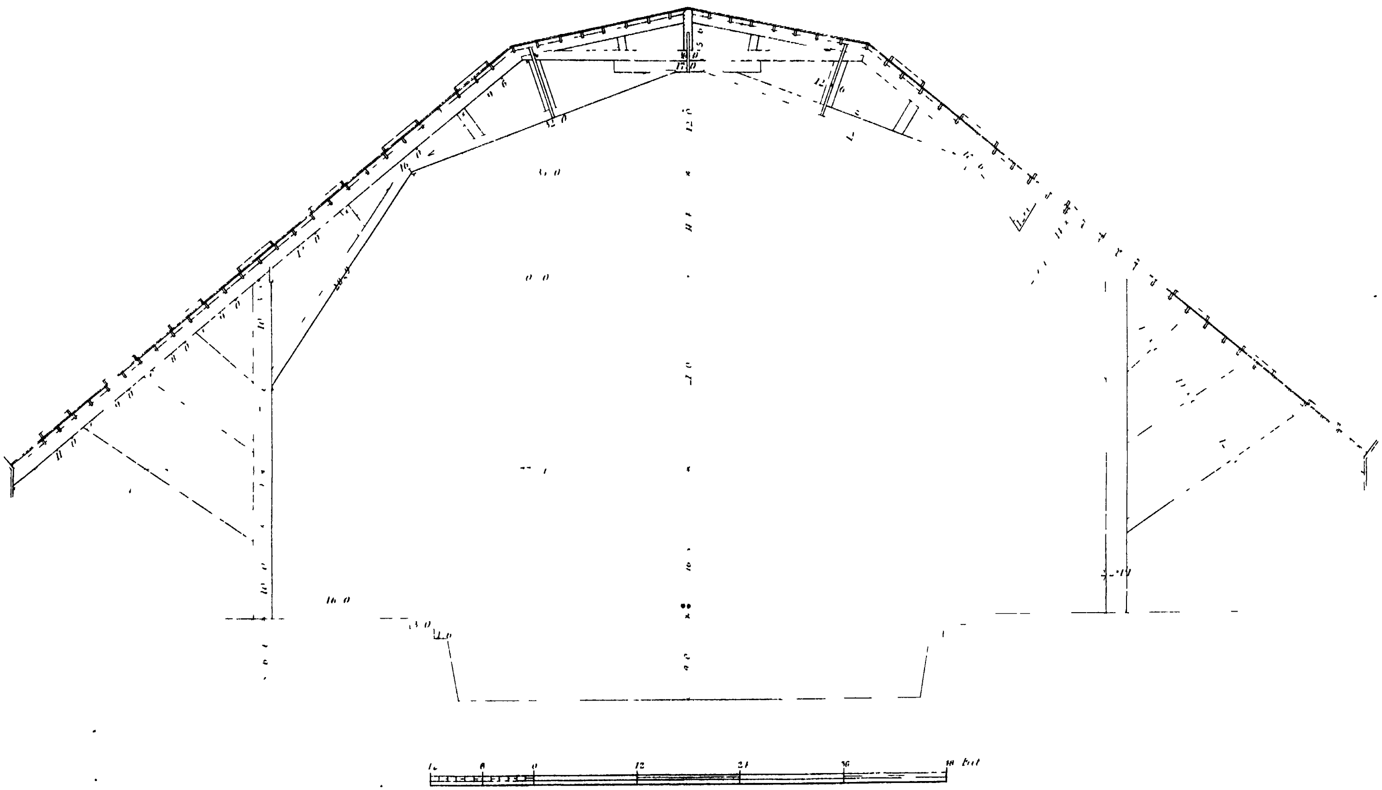
A very neat and even architectural effect is given to the roofs by the cast iron capitals and bases: they are made in two pieces, and are bolted to the standards.

Having, I believe, noticed the most remarkable features in the construction and erection of these magnificent roofs, I shall only add, that the judgment and ingenuity displayed in working out the details through the various complications entailed by their being on an inclined plane, reflect the highest credit on the well-known talents of Messrs. Fox, Henderson, and Co., which have been most ably seconded by the science and ready resource of Mr. J Hughes, who successfully overcame the many difficulties inseparable from the carrying out of so novel and extensive an undertaking.

M WILLIAMS,
Captain, Royal Engineers

Pembroke Dockyard, 25th June, 1845

Section of Wooden Roof over Building Slip in H.M. Dock Yard, Pembroke.

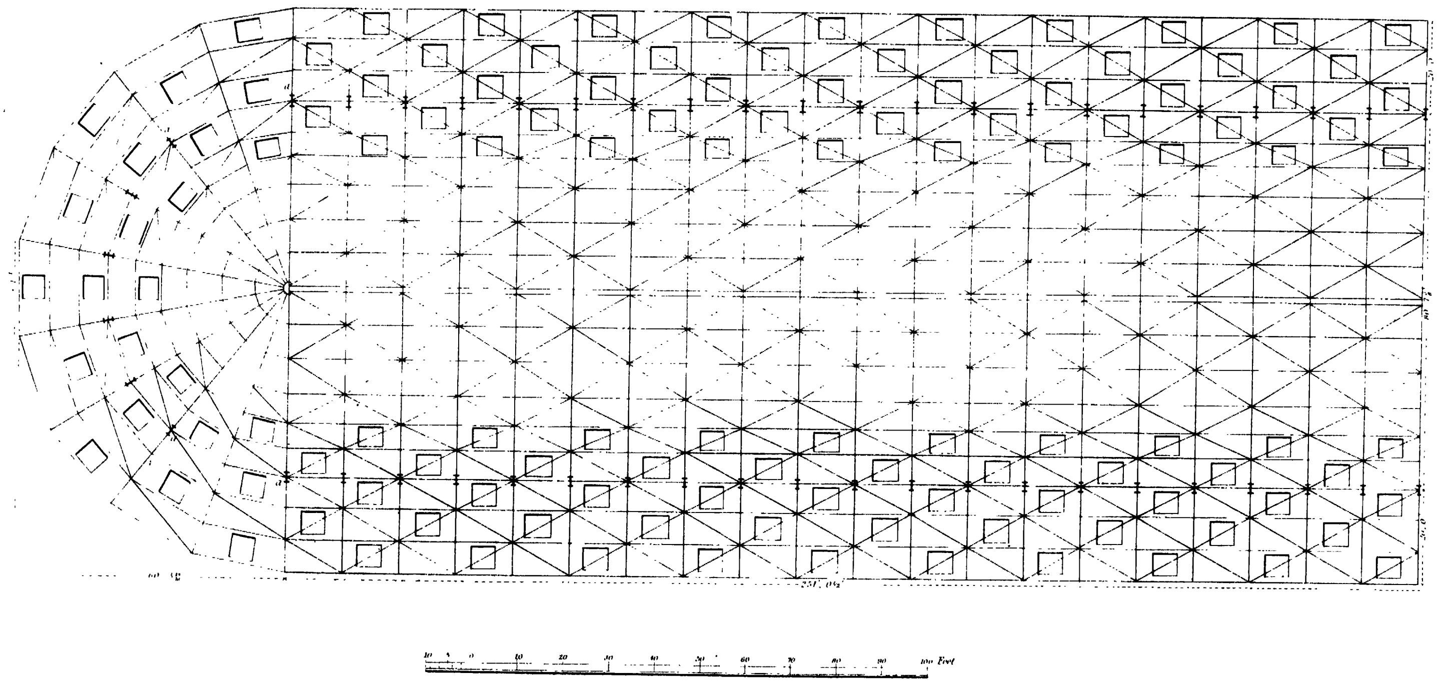


J. Mc Ilpin delt

R.R. Davies sculpt

London, John Weale, Architectural Library, 59 High Holborn

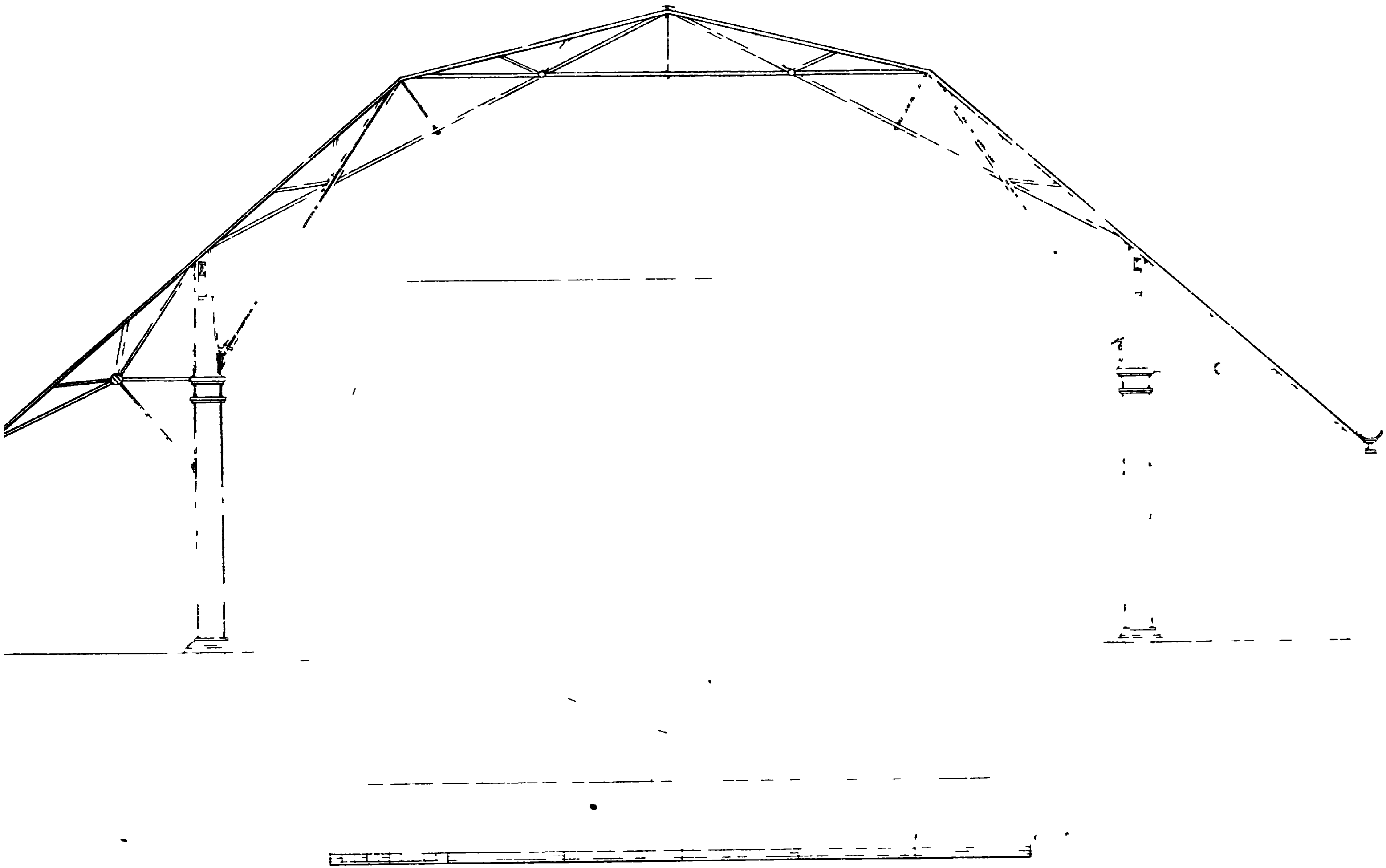
Plan of Iron Roof over Building Slip in H. M. Dock Yard, Pembroke.



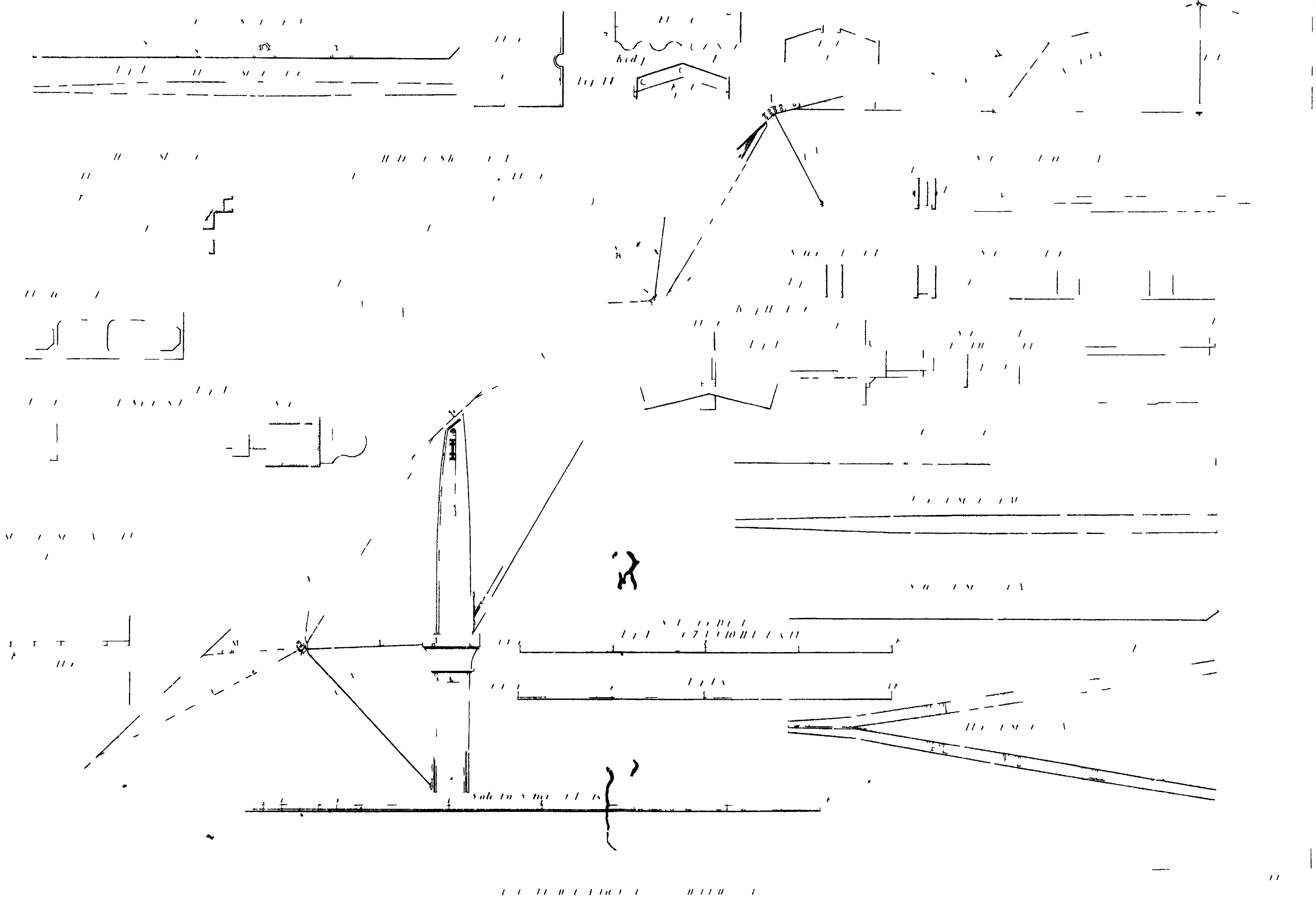
J. R. Davies. Lith.

London, John Weale, Architectural Library, 59 High Holborn

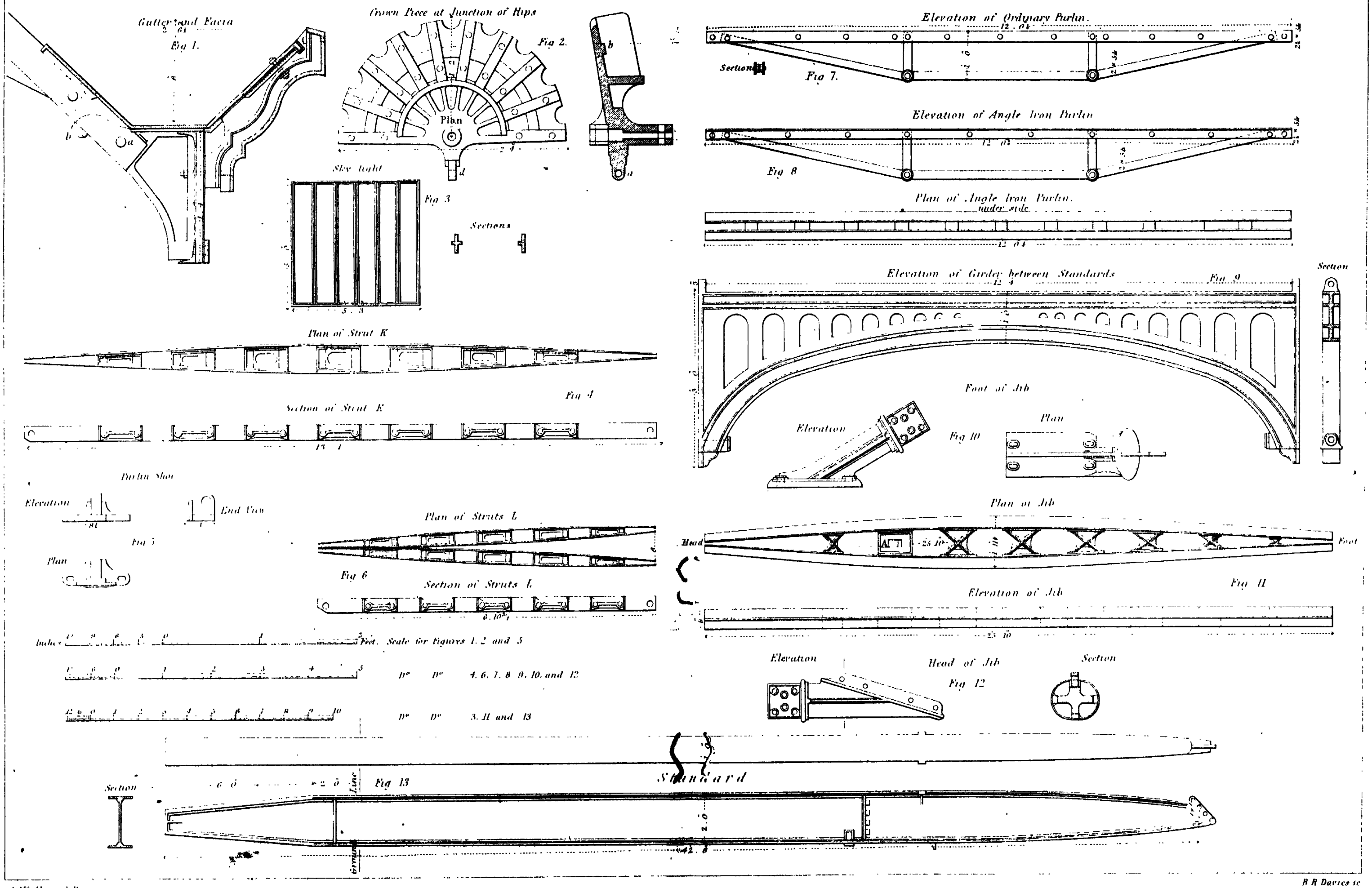
Section of Iron Roof over Building Slip in H.M. Dock Yard Pembroke



DETAILS OF IRON ROOF OVER BUILDING SLIP IN H M DOCK-YARD PEMBROKE



DETAILS OF IRON ROOF OVER BUILDING SLIP IN H.M. DOCK YARD, PEMBROKE.

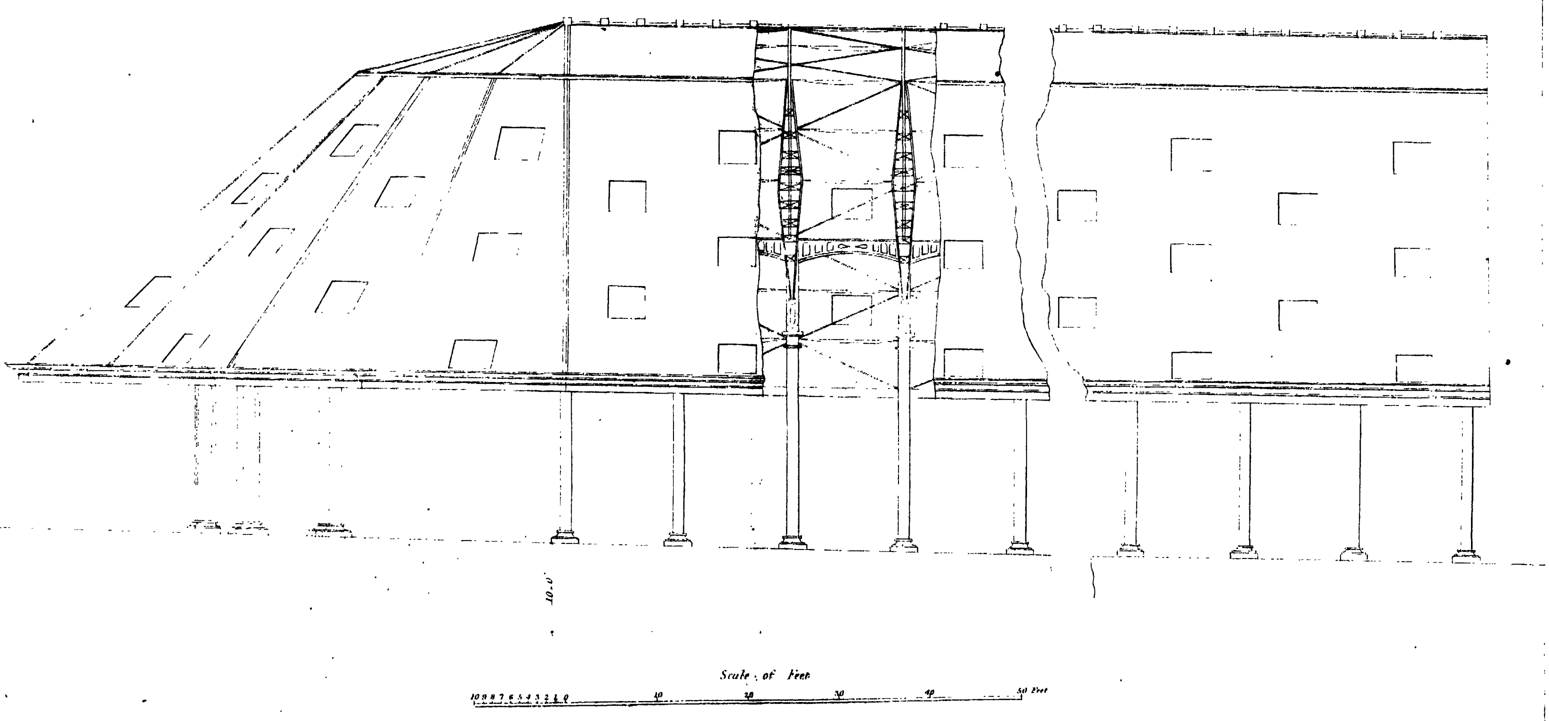


A McAlpin, delt

R R Davies sc

London. John Weale, Architectural Library, 59 High Holborn

Longitudinal Elevation & Section of Iron Roof over Building Slip in H. M. Dock Yard. (Pembroke.)



J. M. Ripon del.
R. R. Davies sculp.

London. John Weale, Architectural Library, 59 High Holborn

VI.—*Iron Roofs erected over Building Slips, Nos. 3 and 4, in Her Majesty's Dockyard, Portsmouth.*

A CONTRACT having been entered into in September, 1845, with the Lords Commissioners of the Admiralty, by Messrs. Baker and Son, of Lambeth, for the erection of two cast and wrought iron roofs (as delineated in Plates XVI. and XVII.) over two first-class ship-building slips in this Dockyard, their erection was begun in the early part of the succeeding December; and it is proposed, in describing the several figures in the Plates, to trace their execution from the commencement, through the various successive stages, to completion.

The castings, having been prepared elsewhere, were brought round in vessels to the wharf immediately adjoining the site; and in the space between the proposed lines of standards of the two roofs, a timber scaffold having been erected, with sufficient projection beyond the sea wall to carry a travelling crane over the hold of the ship alongside, they were hoisted out, and carried at once to convenient positions on the work.

The excavation for the standard pits having been made, concrete, formed of seven measures of clean ballast to one of lime, was thrown in, forming a bed 3′ 0″ in depth for a Roache Portland step-stone, 4′ 0″ × 4′ 0″ × 2′ 0″ thick. The standard (weighing about 3 tons) was then hoisted into place, and stepped 6 inches into the stone, concrete being again thrown in to form a mass around it, 8′ 0″ × 7′ 0″ × 4′ 3″ deep. Upon this a height of 2′ 0″ of brick-work in cement was brought up to receive a granite curb, 1′ 3″ deep and 2′ 0″ wide, all around the base of the standard at the ground line.

Six standards to each roof, three on each side, 84′ 6″ from centre to centre, measured transversely, and 30′ 0″ from centre to centre, measured in the

length, (see figs. 1 and 2, Plate XVI.,) having been thus fixed, the moveable scaffold (figs. 3 and 4), for which the whole of the timber framing had been previously prepared, was then put together, the iron standards being used as temporary stays during its erection. It was constructed in four heights, the first stage being at about 25′ 0″ from the ground line, and the second, third, and fourth at 40′ 0″, 50′ 0″, and 60′ 0″, respectively. A baulk of timber was laid longitudinally on each side, upon which the sill of the scaffold was set, and from thence the structure framed as shown in the drawings. The posts, rails, and struts were all firmly bolted and braced together, and the whole securely tied by longitudinal and transverse chain-ties. The overhanging platforms to the first and second stages were supported by struts from below, 5″ × 4″, and slung by chains from the main rails above, having a projection for the first of 12′ 0″, and for the second of 8′ 0″ from the main post.

The upper part of the scaffold being complete, the whole was lifted to a height sufficient to admit of the cast iron frames and wheels (*a*, *a*, *a*, fig. 4) being got under and fixed to the sill, three on each side; and wrought iron trams being then laid upon the longitudinal baulks, the wedges were knocked away, and the scaffold lowered into its position, to be drawn along from bay to bay, through the whole length of the roof, as the progress of the work rendered necessary.

One month having been expended in landing the materials, erecting the scaffolds, and making the necessary general preparations, the construction of the roofs proceeded at the rate of one bay of both roofs per week.

Each half of the main truss of the roof is formed in three distinct divisions, F, G, and H, fig. 10, Plate XVII.

1st. The casting (F), composing the upper standard, half the spandril, and the upper part of the overhang, having (as is the case throughout) wrought T iron ribs riveted by $\frac{3}{4}$-inch rivets to its upper and lower flanges (fig. 11), is hoisted into place, halved over and secured to the cap of the main standard below by three $1\frac{1}{4}$-inch and four $1\frac{1}{2}$-inch bolts, heads, and nuts.

The longitudinal girder at the springing (from standard to standard, fig. 18), the centre post upon it, and the cast purlin at its head, are then immediately fixed, diagonal ties $2\frac{1}{2}'' \times \frac{1}{2}''$ bracing the whole.

2nd. The upper half spandril (G) is next added, and is bolted to the lower casting, already fixed, by $\frac{3}{4}$-inch bolts, the wrought T irons being, as before described, already riveted upon it. These ribs break joint past the junction of

the castings and the coupling-pieces connecting the whole, which latter are 14 inches long × $5\frac{1}{2}$ × $\frac{3}{8}$ inches, riveted with six $\frac{3}{4}$-inch rivets.

3rd. These operations being simultaneous on both sides, the next step is to key the whole by the addition of the crown-piece, composed of two castings (H) bolted together on the centre line by $\frac{3}{4}$-inch bolts, the wrought iron coupling-pieces being again added. The junction between the spandril and crown-pieces is formed entirely of wrought iron, for the sake of imparting a certain amount of elasticity to this point, whither any action in the centre and higher portions of the roof would resolve itself, if, as ought to be the case, the standards and the castings attached to them remain rigid and unyielding. Here the lines of the flanges of the two abutting castings are carried through in two pieces of wrought iron, $5\frac{1}{2}'' \times \frac{3}{4}''$, welded together and tapered; forming in the centre the mitred intersection of the flanges of the spandril and crown-pieces, (see fig. 16.) In this welding the section of iron (fig. 17) is $7'' \times 1\frac{1}{4}''$ exclusive of the T ribs above and below it. The butt joints of the wrought and cast iron are joggled or filled in solid with wrought iron spandril or wedge-pieces, breaking the joints and making good the interstice formed by the tapering of the wrought iron mitring before described. The whole five thicknesses are riveted through with four $\frac{3}{4}$-inch rivets, extending above, below, and between the two butts of the adjoining castings.

The tie from standard to standard being now perfected, the first overhanging casting (I) is fixed to the outside of the upper standard, and to the main truss of the roof, by a cast filling-piece (K). To these are bolted the eaves casting (L), to carry the gutter, the wrought T irons and coupling-pieces being added as before; thus completing the upper rib from ridge to eaves, as the lower had before been perfected from standard to standard.

Two principals having been thus erected, the next step is to fix the trussed purlins (fig. 1, Plate XVII). They are formed of $\frac{3}{8}$-inch rolled angle iron, 4 inches deep, and turned up 2 inches to receive the corrugated iron covering, (making its greatest depth 5 inches,) trussed by cast iron struts and wrought iron tie-bars, $1\frac{1}{2}'' \times \frac{4}{16}''$, secured at the bearings by $\frac{3}{4}$-inch bolts (fig. 2), which also fasten them in cast iron ⊣ traps (D). These traps, when the whole is hoisted into place, are in their turn bolted by $\frac{3}{4}$-inch bolts to the upper ⊥ of the main rib, fig. 3. These and the trussed ridge (figs. 12 and 13), which is similar in construction but stronger in detail, having been fixed, the sheets of galvanized corrugated iron are laid on and riveted to them by $\frac{1}{4}$-inch button-

headed and galvanized rivets and washers, one to every corrugation in the width, and 8 inches apart down the length of the sheets. The corrugated iron used is of No. 18 guage, averaging in weight, inclusive of rivets, washers, &c., about 232 lbs. per square.

A question having arisen as to the strength of the purlins constructed according to the foregoing description, and their capability to bear the weights and pressures to which they might be subjected, an experiment was instituted by order and under the instruction of Captain Sir Wm. Denison, R.E., F.R.S., the late Director of Works in this Dockyard, and the following were the measures taken and the results elicited.

Two purlins having been bolted to two stout logs of timber (laid transversely and notched down upon two others), in manner precisely similar to that in which they would have been fixed to the principals of the roof, a sheet of iron turned up at its edges was riveted to the upper faces of them, as the corrugated iron would have been in actual practice. A batten was then laid over the upper face of each purlin and against the turned-up edge of the iron plate, which prevented it from slipping; and upon these battens was laid the boarding upon which the weights were to be placed.

In order to measure the deflection, four battens were fixed across the purlins at the points where the struts of the truss supported it, and the measurements were taken from the under side of these battens to fixed points below them, on the application of every twenty pigs of ballast, except towards the end of the experiment, when the increasing load was reduced to ten pigs at a time.

Each pig of ballast weighed on an average 114 lbs., one hundred and sixty having been weighed to obtain the mean. These pigs were distributed as equally as possible over the whole surface supported by the two purlins, short struts being placed against the two sides, to prevent any lateral motion.

The details of the experiment, showing the weight applied and the deflection at the several points occasioned by it, are shown in the following Table. The battens were placed at A, B, C, D (fig. 19, Plate XVII.), equal loads having been placed between the corresponding distances.

No. of Experiment.	Weight applied.		North Side. Deflection at the Points A	Defl.	B	Defl.	C	Defl.	D	Defl.	South Side. Deflection at the Points A	Defl.	B	Defl.	C	Defl.	D	Defl.
	cwt.	lbs.																
1	20	40	$6\frac{3}{8}$	$\frac{4}{8}$	$7\frac{3}{8}$	$\frac{3}{8}$	$7\frac{1}{2}$	0	$7\frac{1}{4}$	$\frac{1}{8}$	$6\frac{7}{8}$	$\frac{2}{8}$	$6\frac{3}{4}$	$\frac{3}{8}$	$7\frac{1}{4}$	$\frac{6}{8}$	$7\frac{1}{4}$	$\frac{5}{8}$
2	40	80	$6\frac{1}{8}$	$\frac{2}{8}$	7	$\frac{3}{8}$	$7\frac{1}{2}$	$\frac{4}{8}$	$7\frac{1}{8}$	$\frac{2}{8}$	$6\frac{5}{8}$	$\frac{1}{8}$	$6\frac{3}{8}$	$\frac{2}{8}$	$6\frac{1}{2}$	$\frac{2}{8}$	$6\frac{3}{8}$	$\frac{2}{8}$
3	60	100	$5\frac{3}{4}$	$\frac{2}{8}$	$6\frac{5}{8}$	$\frac{3}{8}$	7	$\frac{2}{8}$	$6\frac{7}{8}$	$\frac{3}{8}$	$6\frac{1}{2}$	$\frac{4}{8}$	$6\frac{1}{8}$	$\frac{5}{8}$	$6\frac{1}{4}$	$\frac{5}{8}$	$6\frac{3}{8}$	$\frac{4}{8}$
4	81	48	$5\frac{1}{2}$	1·0	$6\frac{1}{4}$	$1\frac{1}{4}$	$6\frac{3}{4}$	$1\frac{1}{4}$	$6\frac{1}{2}$	$\frac{6}{8}$	6	$\frac{1}{8}$	$5\frac{1}{2}$	$\frac{3}{8}$	$5\frac{5}{8}$	$\frac{4}{8}$	$5\frac{7}{8}$	$\frac{3}{8}$
5	101	88	$4\frac{1}{2}$	$\frac{5}{8}$	5	$\frac{6}{8}$	$5\frac{1}{2}$	$\frac{6}{8}$	$5\frac{3}{4}$	$\frac{4}{8}$	$5\frac{7}{8}$	1·0	$5\frac{1}{8}$	$1\frac{1}{8}$	$5\frac{1}{8}$	$1\frac{1}{8}$	$5\frac{1}{2}$	$\frac{7}{8}$
6	111	108	$3\frac{7}{8}$	$\frac{3}{8}$	$4\frac{1}{4}$	$\frac{4}{8}$	$4\frac{3}{4}$	$\frac{2}{8}$	$5\frac{1}{4}$	0	$4\frac{7}{8}$	$\frac{2}{8}$	4	$\frac{3}{8}$	4	$\frac{6}{8}$	$4\frac{5}{8}$	$\frac{5}{8}$
7	122	16	$3\frac{1}{2}$	$\frac{2}{8}$	$3\frac{3}{4}$	$\frac{2}{8}$	$4\frac{1}{2}$	$\frac{2}{8}$	$5\frac{1}{4}$	$\frac{3}{8}$	$4\frac{5}{8}$	$\frac{1}{8}$	$3\frac{5}{8}$	$\frac{4}{8}$	$3\frac{1}{4}$	$\frac{6}{8}$	4	$\frac{3}{8}$
Breaking Weight	132	36	$3\frac{1}{4}$		$3\frac{1}{2}$		$4\frac{1}{4}$		$4\frac{7}{8}$		$4\frac{1}{4}$		3		$2\frac{1}{2}$		$3\frac{5}{8}$	
Total Deflection				$3\frac{3}{8}$		$3\frac{7}{8}$		$3\frac{4}{8}$		$2\frac{3}{8}$		$2\frac{3}{8}$		$3\frac{6}{8}$		$4\frac{6}{8}$		$3\frac{5}{8}$

The deflection appears to have increased very rapidly on the north side by the fourth load, and on the south side by the fifth load; the weight, however, appeared to be applied unequally.

When the weight shown by the Table, 132 cwt. 36 lbs., was applied, the deflection became very irregular, and there were symptoms of fracture; the south side having visibly deflected more than the north. This weight was left on for ten minutes; as, however, it did not seem to produce any immediate effect, 5 cwt. more was placed upon the truss; and the side struts, which had given some support by their friction, being started, the whole sunk gradually at first, until the cast iron trap broke, when of course the experiment was at an end.

The centre tie of the truss, from F to G, was elongated $1\frac{1}{4}$ inch. The end tie-rods (E, F, and G, H) were scarcely elongated at all, certainly not more than $\frac{1}{16}$th of an inch. This may be accounted for by the mode in which the truss was framed. A, B, F, and C, D, G, being formed of iron strongly bolted together at the angles, were incapable of changing form to any appreciable extent; and E and H being fixed points upon which the truss turned, the point C must have descended lower than D, and A than B, in which case the point G would have been brought nearer to H, and F to E.

It is therefore evident that the whole strain was thrown upon the centre bar, and consequently that it would have been proper to make that bar of a section greater than the others.

The whole area of roofing supported by one purlin is 30′ 0″ × 9′ 6″=285 square feet. The weight of the covering is rather less than 2¼ lbs. per square foot; but to this must be added the weight of snow or other matter which might be expected to rest upon it, together with the effect of the wind to which it would be subjected.

The pressure of the heaviest gale of wind known in this country is about 13 lbs. to the square foot; but this is its horizontal force in a direction perpendicular to its line of transit, and such force will consequently be diminished when acting against a roof, in the proportion of the sine of the angle made by the slope of the roof with the horizon, to radius, which in this case is as one to two.

The greatest actual force then for which it is necessary to provide will be 6½ lbs. per square foot, which, with the 2½ lbs. already given, will make a total weight of 9 lbs. per square foot, or 2565 lbs. upon each purlin, exclusive of snow, &c.

It has been customary to calculate upon a total weight of 40 lbs. per superficial foot, from which, however, in this case a deduction must be made for slating and its accompaniments, to be taken at about 12 lbs. per foot, giving a remainder of 28 lbs., or a total weight upon each purlin of 7980 lbs., whilst the breaking weight was shown to be only 7410 lbs. The purlin, then, although it might be sufficient to meet any but an extreme liability, is not so strong as the customary estimate requires. Sir William Denison therefore considered it expedient to strengthen the trusses by increasing the section of their centre tie-bars, and by adding to the thickness of metal in the cast iron traps,—a course which, in obedience to his directions, has been pursued.

The sky-lights, of which there are twelve in each bay, are 7′ 0″ × 4′ 0″; the frames being of cast iron, with wrought iron bars, 7 inches apart; the upper and lower rails being cast to fit the corrugations of the covering, which laps over the former and under the latter, and to which the sky-light is riveted all round by ¼-inch rivets. They are glazed with "No. 2 patent crown glass, extra thick."

The ridge-roll is formed of galvanized sheet iron, lapping down twelve inches

Iron Roof over Building Slip No. 3. H.M. Dock Yard Portsmouth.

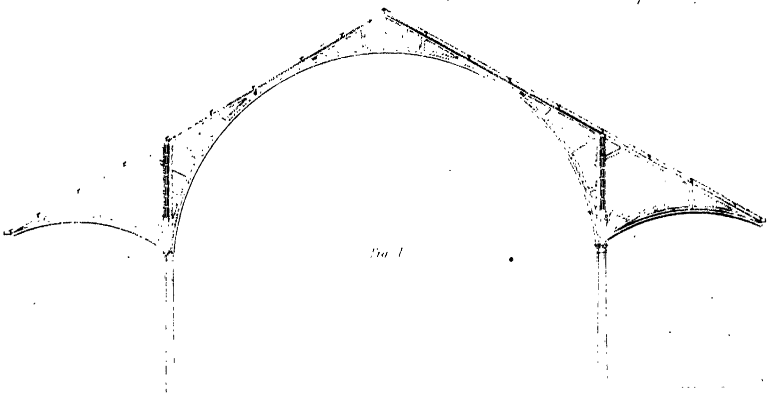


Fig. 1

Transverse Section

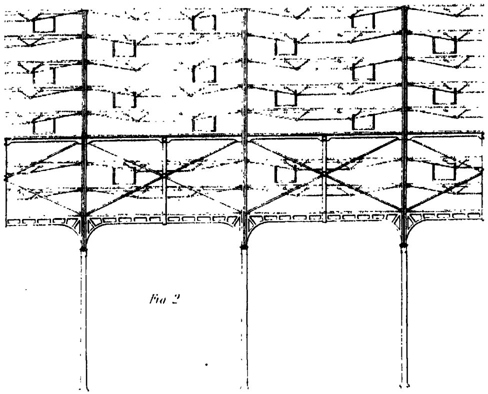


Fig. 2

Longitudinal Section

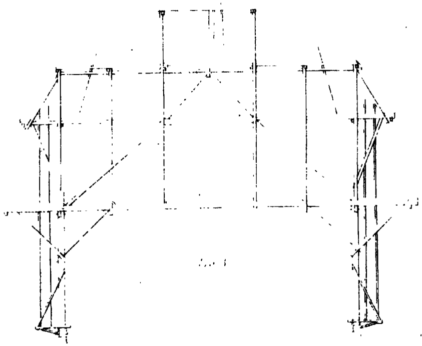


Fig. 3

Skeleton Section of Roof.
Shewing Elevation of Erecting Scaffold

Scale of Feet
10 5 0 10 20 30 40 50

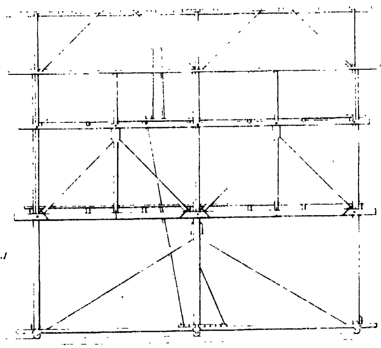
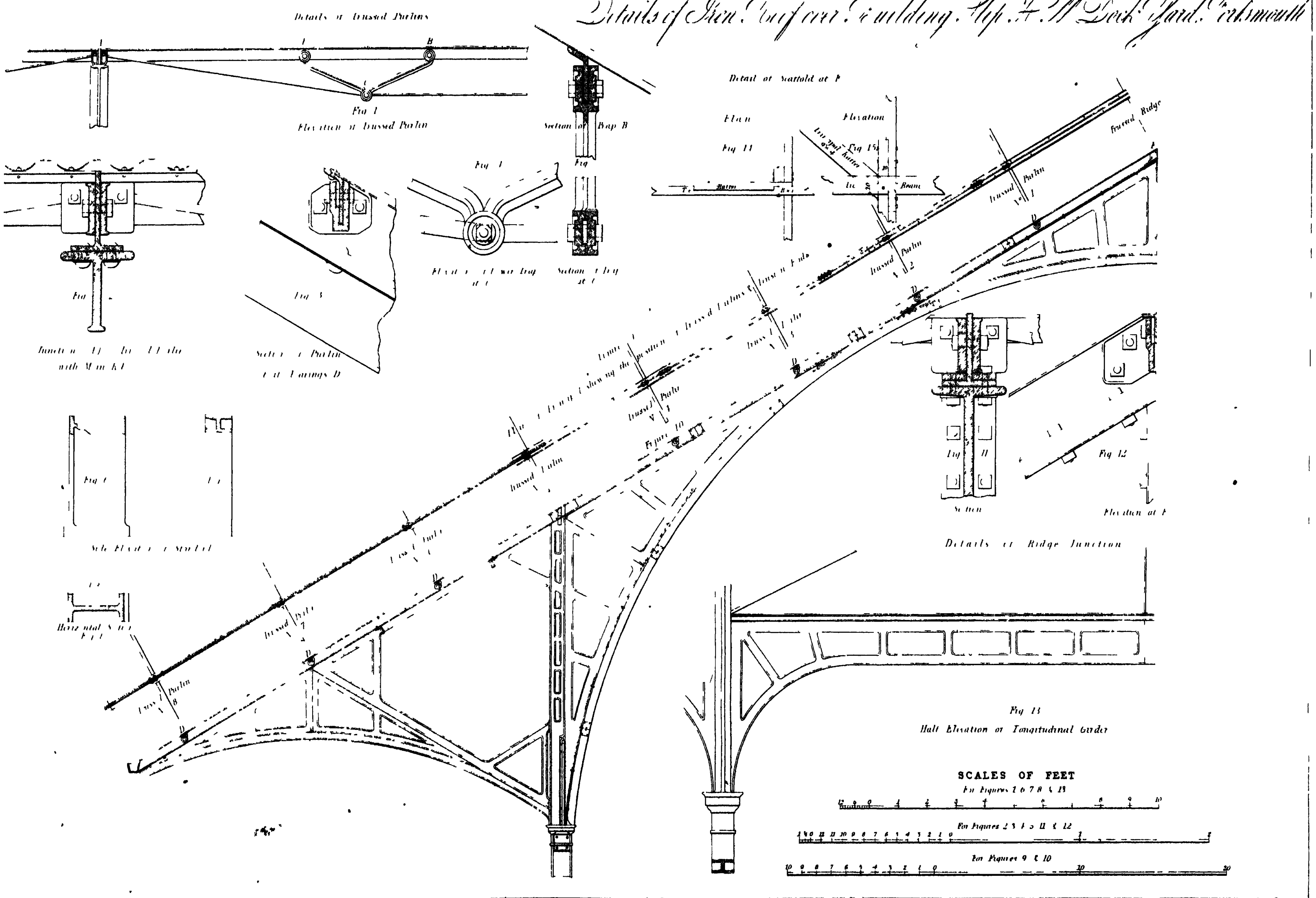


Fig. 4

Skeleton Section of Roof
Shewing Longitudinal Elevation of Erecting Scaffold

London John Weale Architectural Library, 59 High Holborn

Details of Iron Roof over Building Slip No. 4 H.M. Dock Yard Portsmouth



on each side, and dressed over the corrugated iron, which had before been riveted upon the trussed ridge.

The gutters are formed of the same material as the ridge-roll, turned up under the corrugated iron, and riveted to it, the lengths lapping over at the ends, where they are also riveted.

Wind-ties were introduced of ¾-inch round iron, leading from the lower parts of one principal to the higher parts of the next, and tying the whole of the covering down to the principals, in order to resist any lifting power which the wind might exercise from beneath.

The whole of the work not galvanized was painted three times in the best oil colour

The cost of the two roofs, exclusive of the standard pits, which were executed wholly by the Crown, amounted to £14,292. 15*s*.

The superficial area of ground covered amounts to 708 squares, which gives a cost per square of £20. 3*s*. 9*d*.; or, taking another method of measurement, viz., the superficial area of roofing, which amounts to 826 squares, the cost of *covering* given is £17. 6*s*. per square.

To these have subsequently been added gable and side enclosures, but as they are dependent wholly upon local circumstances, they have not been included in the drawings, description, or estimate.

FREDERIC W. CUMBERLAND.

Portsmouth Dockyard,
November, 1846.

VII.—*Description of a Water-Course, Wharf, and Water-Wheel, erected at Waltham Abbey, Essex, in* 1845, *with some account of the Mode of Construction. Communicated by Captain* Crawley, *R. E.*

Among the various duties which the Officers of the Corps of Royal Engineers are liable to be called upon to perform, the construction of water-wheels, and the machinery connected with them, is probably one of the least frequent, and will therefore be my apology, if apology is necessary, for submitting this Paper to the Corps.

Soil.—The valley through which the River Lea flows, the waters of which supply the power for the Royal Gunpowder Manufactory at Waltham Abbey, is subject to frequent inundations, and water is found a very few feet below the surface of the ground at all times. The soil, for an average depth of from 3 to 5 feet, is a rich loam; immediately below is a bed of gravel. It however not unfrequently happens that a soft bog earth is found in spots, varying in depth considerably.

At the site of the works erected in 1845, to replace the buildings destroyed by explosion in 1843, one spot only of this bog earth was found, 20 feet in length and 7 feet deep. The bog earth was removed for a sufficient width to insure the stability of the work, and the cavity filled up with concrete to the same level as the adjoining gravel-bed.

Foundations.—To save the expense of coffer-dams, the mill-head was lowered to get in the foundations of the water-course and wharf. The footings were thus constructed, viz.

Footings, Plate XX., figs. 1 and 2.—Oak gauge-piles $10' \times 8'' \times 6''$, shod with iron, were driven in by means of a ringing pile-engine, at every 10 feet in length of wharf, both in front and rear of the water-course, to which was framed a string-piece of oak, $12'' \times 9''$, bevelled on the outside to the same slope as the wall was proposed to be built, namely, 1 inch to 1 foot. Sheet piling of 4-inch

elm, 12 feet long, jointed and shod with sheet iron, was driven in and spiked to the string-piece.

Land tie-piles were then driven in at every 10 feet in length, of oak, 9′ 6″×8″×6″, shod with iron, to which a 3-inch oak plank, 12 inches wide, was nailed. An iron plate, 4″×½″, was let in all along the face of the sheet piling in front of the string-piece, and 1-inch iron bolts passed through; the whole fastened with nut and screw upon the oak plank in rear of the land tie-piles. Iron bolts, ¾-inch, with nuts and screws, were placed at intervals between the gauge-piles, through the iron plate and string-piece, binding the whole firmly together.

The excavation was carried 3 feet below the level of the tops of the gauge-piles, and the space filled in with concrete formed of lime and river ballast, the proportion being 1 of Dorking lime to 6 parts of ballast, which contained a good proportion of sand.

Water-Course.—The foundations of the side walls of the water-course were placed on 3 feet of concrete, based upon the gravel. The fall-stones and apron were also laid upon concrete, as also the side of the water-course opening into the mill-head.

The fall of water is 6 feet, and the radius of the curve is 8 feet, from the centre of the water-wheel to the extreme point of the start. The stones forming the lower courses of the fall were then laid, the exact curve being kept by a trammel of 8 feet radius, hung in the position of the shaft of the water-wheel, and moving on a centre. The fall-stones were set in Harwich cement, grooved, and run with lead.

Upon the concrete, and under the fall-stones and 3-inch York landings brick-work was built in cement (Plate XIX., section, fig. 1).

The wash-stones at the sides of the fall were next placed. The walls to support the plummer-blocks were built 3 feet thick, of brick-work in cement; the side walls 2′ 3″, and the walls enclosing the pit-wheels two bricks thick.

The crown-stones were then set, and the remainder of the masonry to complete the fall was built, including the side-stones, which were sunk to receive cast iron rebates in which the gate works.

The entrance to the water-course is of masonry; the sill laid perfectly level, and rubbed off smooth, so that the planking forming the stop-gate may lay close upon it The quoins are sunk to receive cast iron rebates, which are fixed, and run with lead.

Wharf.—The walls for 10 feet on each side of the water-course, both above and below the fall, are built of brick in cement. The remainder of the wharf wall is of concrete, faced with 9-inch brick-work in cement, having bonds, at every 5 feet distance from centre to centre, 9 inches in length and two courses deep (Plate XX. figs. 1 and 2). Counterforts of concrete were formed of a dove-tailed shape, at every 10 feet distance from centre to centre. The brick-work and concrete were carried on simultaneously. The whole coped with 3-inch York coping, set in cement, dowelled, and run with lead.

Pumping.—The instant the excavations reached the gravel-bed, the water bubbled up in a thousand springs, which rendered incessant pumping necessary to enable the workmen to get in the foundations.

A temporary water-tight dam was formed across the old tail-stream, and close to it, on the side next the works a well was sunk, 3 feet lower than the level of the foot of the foundation, which drained the water from the works. In this well four pumps were placed, 12 inches square, in pairs, each pair worked by from four to six men at the ends of a lever. These pumps threw about 200 cubic feet of water per minute. The men worked in spells of ten minutes each.

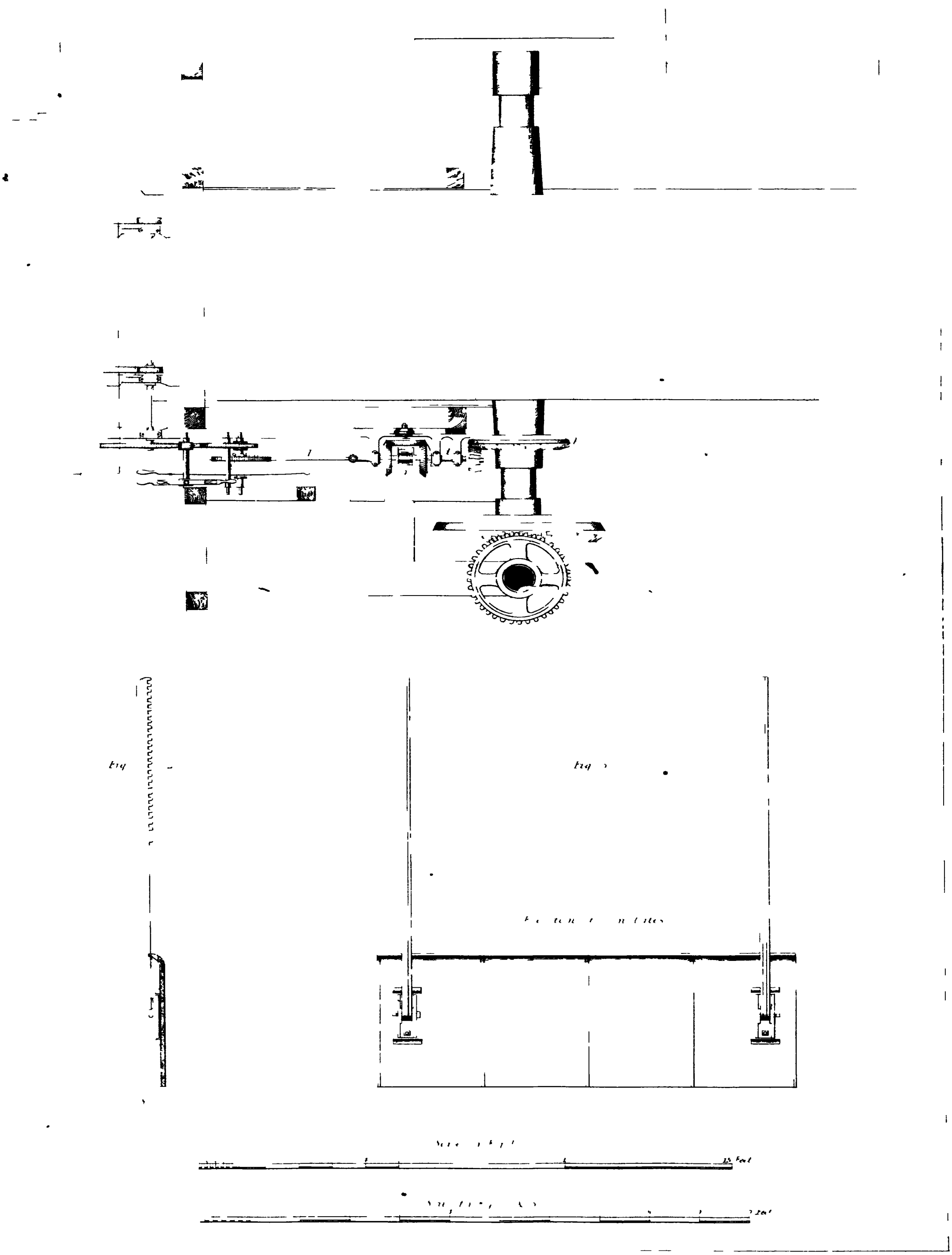
The pumping might have been done more expeditiously and much cheaper by a steam engine, but the vicinity of the gunpowder works rendered such a measure objectionable.

Water-Wheel.—The shaft of the water-wheel is of cast iron and cylindrical, working in bearings of gun-metal 12 inches diameter. The rings of the wheel (Plate XX. figs. 3 and 4) are cast in two semicircles, bolted together, and fixed to the shaft by keys, as shown in the diagram. The starts are of seasoned oak, driven into the ring, and fastened with an iron pin. The floats are of sheet iron, bolted to the starts and water-wheel rings, as shown in the diagram, (Plate XX. figs. 3 and 4,) which it is hoped is sufficiently explanatory without further description.

Gate.—The water-wheel gate (*k*, fig. 1, Plate XIX.) is of cast iron, and is made to sink, instead of being drawn up, to supply the water, thereby affording a greater altitudinal pressure on the floats of the wheel, with the most economical expenditure of water. The elevation and section of the gate are shown in figs. 2 and 3, Plate XVIII. Sinking gates of wood have long been in use, but this is probably the first made of iron.

The breast iron (*a*, fig. 1, Plate XIX.) is cast with feathers on the back, and a

Plan of the Water Wheel at Waltham Abbey



B.R.Davies sculp

Elevation of the Water Wheel & its Regulator, at Waltham Abbey.

Fig. 2

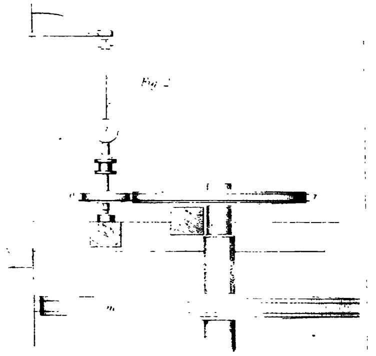
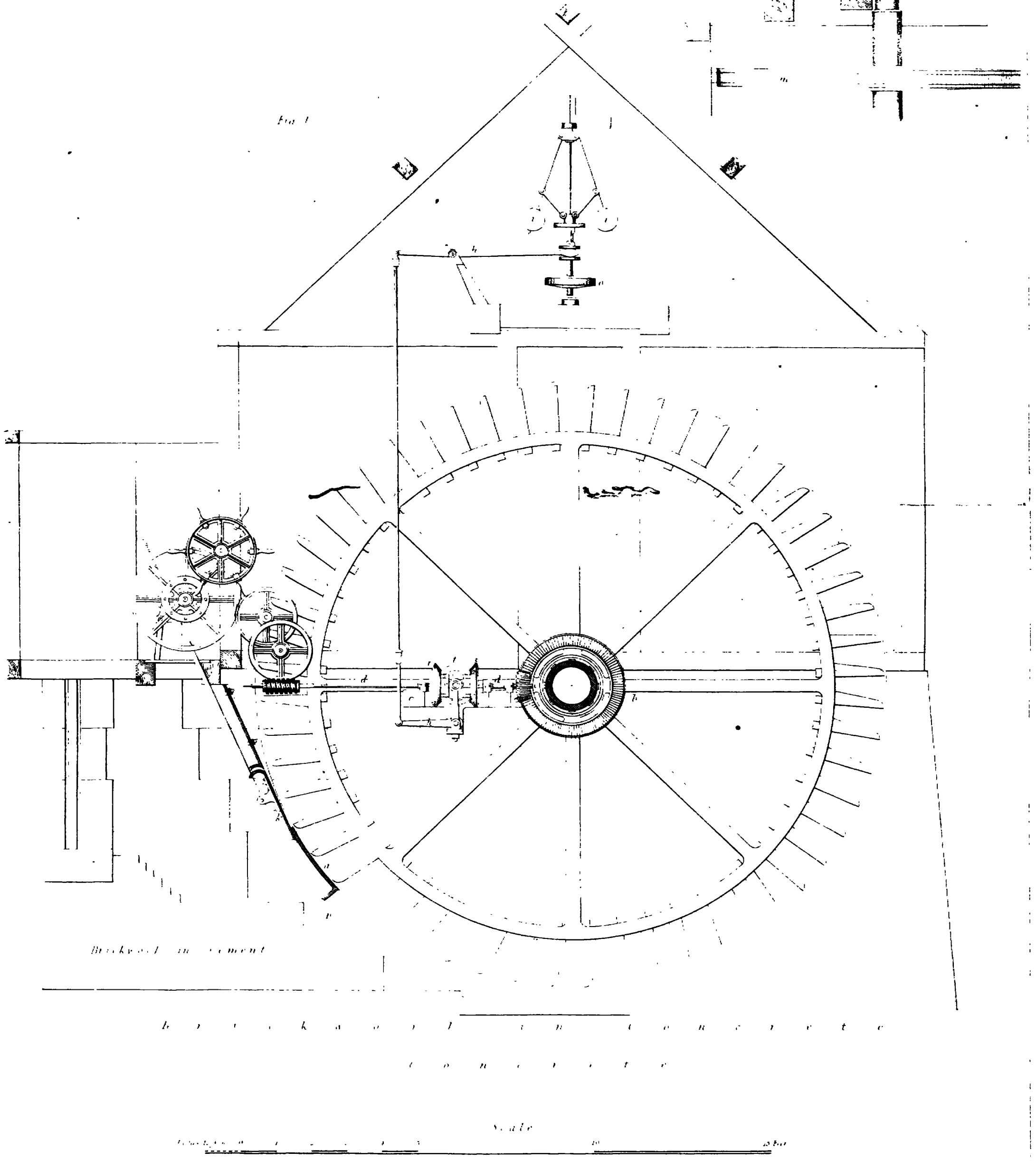


Fig. 1



J. D. Dempsey del. B. R. Davies Sculp.

London. John Weale Architectural Library 59 High Holborn.

Diagram

shewing the method of connecting the two half Water Wheel rings & securing them to the Shaft by Keys also the method of fixing the Starts and Floats

Fig 3

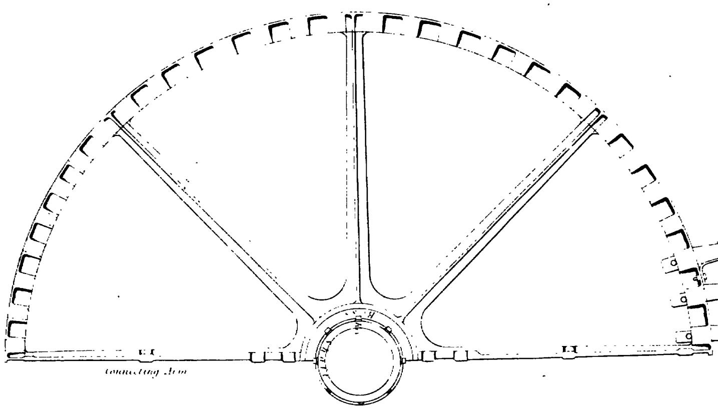
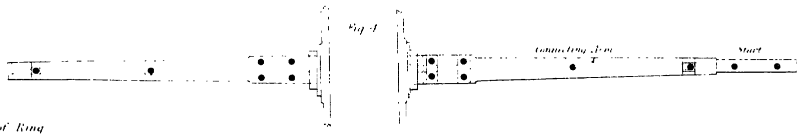


Fig 4



Outside of Ring

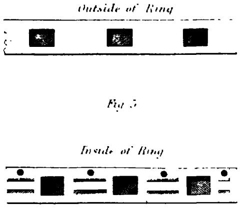


Fig 5

Inside of Ring

Scale 1 Inch to 1 foot

Scale 1½ Inch to 1 foot

PLAN AND SECTION OF THE Wharf Wall, at Waltham Abbey.

Fig 2

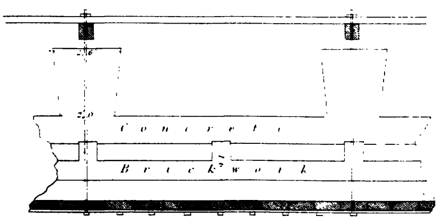
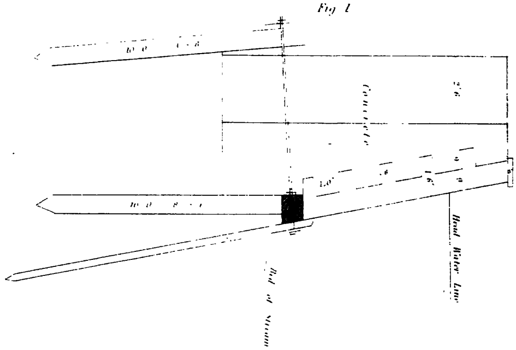


Fig 1



Scale 1 Inch to 1 foot

B R Davies sculp

London John Weale Architectural Library 59 High Holborn

flange at the bottom: this flange is sunk into and strongly bolted to the crown-stone (*p*); the sides are secured by grooves cut into the stone-work.

Those parts of the breast-iron and gate which are in contact when the gate is shut, are planed, and ground together with oil and emery, to make a close joint.

The gate is worked by rack and pinion, as shown in section (fig. 2, Plate XVIII.), and moves up and down in cast iron rebates sunk into the stone-work, the inner surfaces of which are planed.

Regulator.—In all machinery, but especially in that made use of in the manufacture of gunpowder, the regulation of the velocity and uniformity of motion are matters of very great importance, the want of which is felt, either when the force of the first mover is fluctuating, or, which from many causes rivers are liable to, when the sudden variation in the head of water which drives the wheel communicates irregularities to its speed. To counteract these evils, a regulator is attached to the water-wheel, which, acting on the water-gate, causes the whole machinery to move with clock-like regularity.

Plate XIX. fig. 1.—A bevel-wheel (*b*) on the water-wheel shaft, working a pinion (*c*) on the short lay spindle (*d*), and turning a bevel-wheel (*e*) on the same spindle, drives two other bevel-wheels (*f f′*), which are neither of them *fixed* on their spindles, but move freely round upon them.

A clutch (*g*, fig. 1, Plate XVIII.) is connected by levers (*h h*, fig. 1, Plate XIX.) to the governor balls (*i i*), and when the mill is going with its true velocity, remains between the two bevel-wheels (*e f′*) on the lay spindle (*d′*); but on any alteration in the velocity of the mill taking place, the balls open or shut, and cause the clutch to lock the lay spindle (*d′*), and put in motion the wheel-work which is connected with the sinking gate (*k*), which it raises or depresses as required.

Fig. 2, Plate XIX., shows the crown-wheel (*m*), as also a cast iron wheel (*n*) on the same shaft, which acts upon the small iron wheel (*o*), operating upon the governor balls (*i i*).

H. C. CRAWLEY,
Captain, R. E.

Liverpool, 7th February, 1845.

VIII.—*Description of the large Chimney for conveying the Smoke from the various Buildings connected with the Steam Machinery Factory in Woolwich Dockyard.*

The site for the proposed chimney having been determined, the earth was excavated to a depth of about 16 feet, of the form of an octagon 36 feet in its shortest diameter. The upper stratum, for a depth of about 2 feet, consisted of garden mould, beneath which lay a bed of a firm loamy sand, overlying the chalk which occurred, at a depth of 14 feet below the surface; but the upper layer of the chalk being loose and rotten, it was thought desirable to excavate to a more solid bed, which was met with about 2 feet lower. A mass of concrete, composed of one part of Halling lime, with six of river gravel, and one of clean sharp sand, properly wetted, was then poured in hot, and its surface carefully levelled at a depth of 15·7 below the ground line. Upon the concrete were laid and well bedded in mortar, two courses of York landing, 6 inches thick, properly bonded, so as to break joint over the whole surface; these courses forming an octagon 35 feet wide. On these landings were placed the footings of the chimney, the lower footing being 32′ 9″, and the upper one, or that immediately below the plinth, 27′ 6″ in width. The footings were each four courses of brick-work in depth, and of an octagonal form, each one being $4\frac{1}{2}$ inches narrower than the one immediately below it. A stone 1′ 6″ in depth, and of a conical form, was set in the centre of the course of landings, and formed the key-stone to the inverted arch, which served to distribute the weight of the superstructure more equally over the foundations. The internal diameter of the chimney at the springing of the invert or dome was 15 feet, the invert itself consisting of four rings of brick-work, half-brick thick, laid in mortar and grouted, proper provision being made in it for the openings of the smoke-flues upon the alternate faces of the octagon. Externally the chimney was built of an octagonal shape throughout its whole height, but internally it was carried up

of a circular form in plan as far as the upper blocking course, where it assumes the octagonal form, which it preserves to the top.

The first four courses of brick-work, forming the lowest footing, were laid in cement, layers of hoop iron being introduced between the courses, the hoop iron in one course being laid parallel to four alternate sides of the octagon, and in the course above parallel to the other four sides, so as to form a bond in opposite directions. This plan was adopted throughout wherever hoop iron was employed. At every 3 feet in height up to the bed of the cornice, two courses of hoop-iron bond in cement were introduced, as well as under the inverts, and over the crowns of the arches forming the mouths of the smoke-flues, the hooping being laid in parallel lines about 4½ inches from centre to centre. The two courses of brick-work immediately below the plinth, as well as the whole of the backing to the plinth, cornice, and blocking courses, were laid in cement. Above the cornice, hoop-iron bond was introduced at every 6 feet throughout the whole height of the shaft.

The plinth of the pedestal was formed of sixteen blocks of Cornish granite, a stone 6 feet in length being placed in the centre of each side, and the quoin-stones filling up the remainder of the octagon, which corresponded in dimension with the upper footing. The quoin-stones were secured from any tendency to spread, by two ties of bar iron, 2 inches wide by ½ inch thick. Each of these ties consisted of four bars welded together at the angles to form a square nearly as large as could be inscribed in the octagon of the pedestal. Into the upper bed of each quoin-stone was let an inch bolt, its head being countersunk in the granite and run in with lead, the bolt projecting about 1½ inch above the surface. An inch hole being drilled in each of the angles of the iron ties, one of them was dropped over the four alternate bolts, while the other was dropped over the other four, and all secured by nuts. The same method was adopted for securing the quoin-stones of the cornice up to the level of the upper blocking course: the whole of the work had been carried up vertically, but from that line the chimney began to diminish with an uniform taper to the top. The shortest diameter in the top of the blocking course was 23′ 4″, the thickness of the brick-work being 4′ 2″, while the diameter at top of chimney was 8′ 4″, the thickness of the work being 14 inches. The difference in thickness between the top and bottom was obtained by means of sets-off at regular intervals, each set-off being 4½ inches wide, and the sides of the chimney being parallel externally and internally from set-off to set-off

The different thicknesses were arranged so as to avoid the necessity of cutting the bricks.

To insure perfect accuracy in the construction, the chimney was carefully drawn out to the full size upon a level floor, and a plumb-rule made to the exact batter of the sides. Rods were at the same time marked to the dimensions of the inside and outside diameters of the chimney at every 5 feet in height, which served as a check to the width of the chimney during its progress, while, to insure its perpendicularity, a strong beam was fixed across the centre of the chimney at the level of the top of the cornice, the exact centre being marked by a small hole in an iron plate which was screwed to the upper face of the beam. (As the beam, if fixed constantly, would have been an impediment to the ascent of the materials, it was made with a hinge at one end, so as to turn back when not required for the purpose of testing the accuracy of the work.) Every 10 feet in height a heavy plumb-bob was dropped from the centre of the surface on which the workmen were employed, which, by hanging over the hole in the iron plate, proved the correctness of the execution.

The stone-work forming the cornice, cap, &c., was from the Painshaw quarries, in the county of Durham.

A scaffold of the ordinary description was employed in the construction of the chimney up to a height of about 100 feet, from which point it was judged more advisable to build from the interior. Provision was made for raising the materials required for the work in the following manner.

At the height at which the external scaffolding was discontinued, two pieces of timber, 6 inches wide and 9 inches deep, were built securely into the wall at their extremities; they were placed parallel to each other, their centre lines being about 2′ 8″ from the centre of the chimney, and extended from one side of the octagon to the one opposite. In the centre of each of these timbers was fixed, by means of a tenon, 9 inches deep and 1½ inch wide, and a corresponding mortise, an upright standard, 6 inches square and 16 feet long, in the top of which a mortise was taken out of the same section as the tenon at the bottom, and 6 inches in width. These standards were supported on two sides by struts, 5″ × 4″ in section, and 10 feet long, framed into them and into the bearing timbers. On the top of the standards was fixed, by means of a tenon let into it and projecting below it, to correspond to the mortise in the top of the standards, a *cross-piece*, 9″ × 6″ in section, projecting on each side 4½ inches

beyond the standards, an iron strap being passed over the top and bolted to the standards, to render the connection more secure. As the chimney rose in height, and it became necessary to raise the frame-work by which the materials were lifted, the cross-head was removed, and a length of standard of 16 feet, similar in every respect to the first, secured by a tenon and mortise to each of the lower standards, the cross-head being fixed on the top of the lengthened standard, as before described, and so on, until the whole was completed. To lift these standards a small pair of sheer legs was used. It was found, however, as the chimney increased in height, that it was not safe to lengthen the standards more than 9 feet at a time. The scaffolding was constructed in the ordinary manner round the upright framing, by means of pulleys let into the wall, which, being lashed to the standards where practicable, served to stiffen them, and render them more secure. In two or three places in the height of the chimney, where the framing was not found to be sufficiently steady, a couple of beams were laid across the chimney against the sides of the standards, and parallel to the bearing timbers, and their ends securely built into the wall. The standards were then bolted to these stiffening pieces, and the whole frame made rigid.

To the cross-piece were secured two single pulley blocks of iron, over which were passed the ropes carrying the boxes in which the materials were raised. Each of the blocks was made so as to revolve round a bolt passed through the cross-piece, and secured by a nut at the top. The boxes were 1′ 9″ square on the bottom, and 1′ 7″ in depth, and the pulleys were placed in such a position as to allow of their passing each other freely.

A large single-purchase crab, placed at the bottom of the shaft, gave motion to the ropes which carried the boxes. The barrel of the crab was divided by a disc of wood, separating the ascending and descending ropes, which were coiled round the barrel in opposite directions, so that motion being given to it in either direction, one rope was made to ascend while the other descended. By this means the materials required, being placed in the box attached to the ascending rope, were raised to the necessary elevation, the empty box being lowered by the same movement to be filled and raised in its turn.

The brick-work of the chimney being completed, a strong piece of timber, not quite so long as the diameter of the shaft at the top, was fixed on the top of the cross-head in its centre by means of a strong bolt, round which it could be moved in a horizontal direction, serving as a crane for the purpose of

setting the stone-work of which the cap consisted. A block, with a fall attached, was fastened at each end of this timber, one serving to lift the stones while being set, the other being used for the purpose of holding down the opposite end of the beam as a counterpoise to the weight of the stone. The stones of the cap were connected together by lead cramps.

A lightning conductor, formed of a copper tube, 1¼ inch in its outside diameter, was attached to the chimney as the work proceeded. The tubes were cut in lengths of 6 feet (or twenty-four courses of brick-work), and at the joint of each tube, a stone, 9 inches wide by 6 inches high, and 6 inches on the bed, was built into the brick-work. Into the centre of the stone was let in and run with lead a small shoulder of gun-metal, with an eye at the end, of the exact diameter of the tube, and through which it passed. A small bolt of gun-metal, 2 inches long, with a screw at each end, and a projecting shoulder on two sides, served at every joint to connect the upper and lower tubes, rendering the metallic connection perfect, while the shoulder, resting on the metal bracket, caused each bracket to carry the weight of the length of tube immediately above it only. The tube was kept about ½ an inch from the face of the brick-work. Great care was taken in fixing the conductor, to insure the actual contact of each tube with the one below it. The top of the conductor was raised about 6 feet above the top of the chimney, while at the bottom the tube was carried down in a brick shaft, until it reached a point where water is always found a little below the base of the chimney.

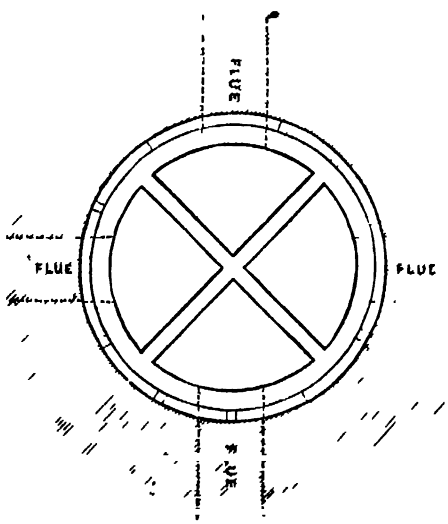
CIRCULAR CHIMNEY.

This chimney, which serves to carry off the smoke from the large smiths' shop, and from the boilers of the engines employed to work the saw machinery, resembles, in all the essentials of its construction, the octagonal chimney just described. In some of the details of the execution a difference was made.

The chalk lying lower in the part of the dockyard in which it was erected, it was necessary to place a layer of concrete of about 3 feet 6 inches thick under the York landings, on which in the other the superstructure rests. Three flues only have mouths in this shaft, instead of four, as is the case in the octagonal chimney. The base of the shaft is formed of a basaltic rock, known as Carlin's nose, from the neighbourhood of Leith in Scotland, and consists of

a massive plinth, 5 feet high, on which is a large torus moulding, surmounted by a fillet. The stones forming the plinth were dovetailed into each other, preventing the possibility of their spreading, so that the tie used in the octagonal chimney was not required. The diameter of the shaft above the plinth is 22′ 6″, the thickness of the brick-work being 4′ 6″; the diameter and thickness at top correspond with the similar portion of the other shaft. The brick-work in this shaft diminishes uniformly the top, internally as well as externally, no sets-off being made in the brick-work, as was the case in the other. To insure the accuracy of the circular form, when the chimney was set out full size, as before described, a mould was taken of the form of the circumference at every height of 10 feet, as a check to the work as it proceeded. Hoop iron in cement was used at the level of every stone for carrying the bracket which supports the lightning conductor up to the height of 100 feet from the ground, after which it was laid in mortar.

In both these chimneys the interiors of the shafts and of the flues leading into them were lined with fire-bricks, in order to secure them from the heat developed by boiler plate furnaces and air furnaces which deliver their smoke into them from no great distances.



In the octagonal chimney, the fire-brick lining was carried up to the level of the top of the cornice: in the circular shaft it terminated at 20 feet above the ground line. A space of 2½ inches was left all round between it and the ordinary brick-work, but was steadied by occasional headers carried through against the brick-work. From the bottom of the invert upwards to about 2 feet above the crown of the arch of the flues, a partition of fire-brick was carried up in each chimney, for the purpose of preventing the draught of the flues interfering with the working of each other. In the octagonal chimney it was divided into four compartments; in the circular, into three.

The price for 4½″ Stourbridge fire-brick lining is 1*s.* 4*d.* a foot, and the cost of the lining in the octagonal chimney was £161. 13*s.* 8*d.*

The object of these chimneys, as has been stated, is to collect into one shaft the smoke from all the fires in their neighbourhood, with the view of discharging it at such an elevation as to render the smoke no longer a subject of complaint by the inhabitants of the neighbourhood. The draught, too, being very great, it was supposed that it would be sufficient to draw down the smoke of the smiths' fires at once into the under-ground flue, which would carry it into the chimney, and would thus get rid of the intolerable nuisance of smoke in the smitheries and other establishments. A great convenience was also anticipated from the absence of the chimney-stacks, which prevent cranes being used in many situations where they would otherwise be very useful.

The draught has proved to be very great, amply sufficient for all the work which has yet been thrown upon the chimney; but there is a much greater amount of work to be done yet, so that neither of the chimneys can be said to have been fairly tried. When the fire was first lighted in the octagonal chimney, there was hardly any draught at all; the flues, being all damp, carried off so much of the heat which should have gone into the chimney. As soon, however, as the flues got dry, the draught became very powerful. A slight expansion took place at the plinth line, which evidenced itself by very minute cracks at each of the joints. These were stopped up after a time, and nothing of the kind has been seen since.

The cost of the chimneys is here detailed; the flues, being altogether separate from the chimneys, are not included in the estimates.

Abstract of the Quantities and Cost of Building the Octagonal Chimney at the west end of the Yard.

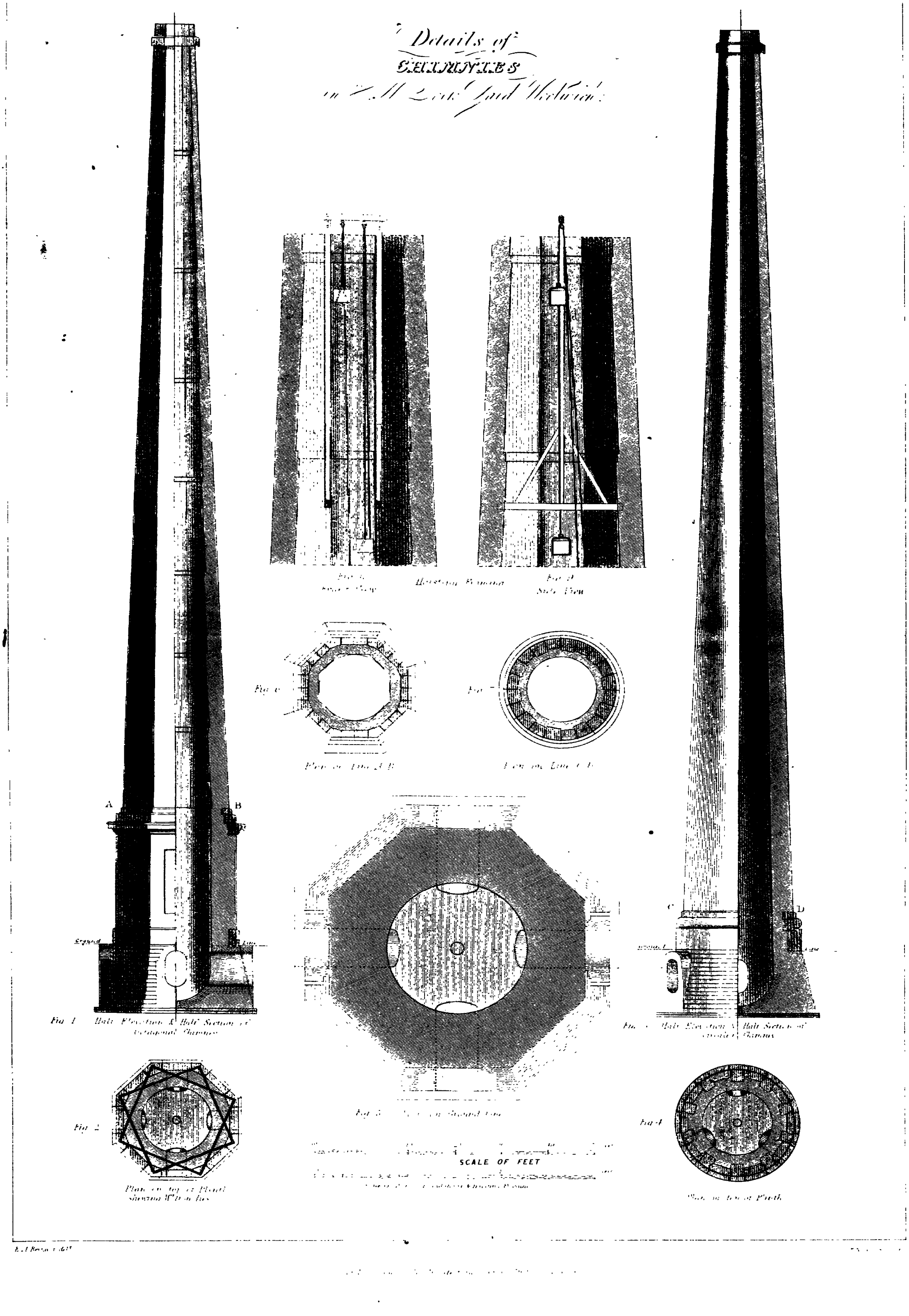
Quantities.	Description of work.	Rate.	Amount. £.	s.	d.
533 yds. ½ ft. . .	Digging in foundations, wheeling, barging, &c. @	3s. 2d.	84	8	10¼
18 yds. 15 ft. . .	Concrete	6s.	5	11	4½
81 rods 69 ft. . .	Brick-work in mortar	£14. 10s.	615	4	1¼
20 rods 78 ft. . .	Do. above 100 feet high	£25.	506	7	5¾
21 rods 288 ft. . .	Do. in cement	£18. 10s.	321	5	5
2934 ft.	Circular face	¾d.	9	2	4½
10,649 ft. 6 in. . .	Picked stock facing	½d.	22	3	4¼
248 ft. 9 in.	Flat joint pointing	1¼d.	1	5	10¾
915 ft. 4 in. cube .	Granite, set complete	2s. 8d.	122	0	10¼
362 ft. 8 in. super. .	Labour to do., on face	11d.	16	12	5¼
756 ft. 5 in.	Do. do. beds and joints . . .	8d.	25	4	3¼
92 ft. 8 in.	Sunk work	1s.	4	12	8
280 pairs	Plug-holes	4d.	4	13	4
1597 ft. 4 in. . .	Bramley Fall stone, set complete . .	1s. 7½d.	128	17	7¼
250 ft. 3 in.	Do. do., in cap, including hoisting . .	4s. 3d.	53	3	6¼
76 ft.	Do.	1s. 4d.	5	1	4
334 ft. 7 in.	Labour on face	7d.	9	15	2
2474 ft. 8 in. . .	Do. beds and joints	5d.	51	11	4
7 ft. 2 in.	Circular work	11d.	0	6	7
550 ft. . . .	Sunk work	10d.	22	18	4
399 ft. 3 in.	Moulded work	2s.	39	18	6
2187 ft. 9 in. . .	York landing, set complete	2s. 8d.	291	14	0
6 cwt. 3 qrs. . . .	Wrought iron in tension-rods . . .	25s.	8	8	9
619 lbs.	Do. in bolts, &c., under 10 lbs. . . .	3½d.	9	0	6½
13½ lbs.	Clasp nails	4d.	0	4	6
	Total		2359	13	[illegible]¼

Abstract of the Quantities and Cost of Building the Great Circular Chimney in Woolwich Dockyard.

Quantities.	Description of work.	Rate.	Amount. £.	s.	d.
470 yds. cube . .	Earth excavated and barged away . . @	2s. 10d.	66	11	8
123 do.	In chalk do. do.	3s. 1d.	18	19	3
141½ do.	Concrete	6s. 3d.	44	10	7¼
50 rods 226 ft. . .	Stock brick-work in Dorking lime . .	£14. 10s.	735	14	2
9 rods 240 ft. . .	Do. in Roman cement	£18. 10s.	180	8	1
23 rods '052 ft. . .	Do. in stone lime above 100 feet high . .	£25.	579	5	2¼
17362 ft. 1 in. super.	Circular face to do.	1d.	72	6	9¼
	Carried forward		1697	15	9¼

Abstract of the Quantities and Cost of Building the Great Circular Chimney in Woolwich Dockyard—continued.

Quantities.	Description of work.	Rate.	Amount. £.	s.	d.
	Brought forward		1697	15	9¾
6482 ft. 10 in. super.	Picked stock facing . . . @	½d.	13	10	1¼
24 ft. 10 in. run.	Cut splay to brick-work	2d.	0	4	1½
42 ft. 6 in. . . .	Circular splay to do.	3d.	0	10	7½
353 ft. 8 in. . . .	Circular rendering in cement, ½″ thick, trowelled smooth	4d.	5	17	10½
2287 ft. 10 in. . .	6″ York landing, set complete . . .	1s. 6d.	171	11	9
4978 ft. 5 in. . .	Labour to beds and joints	4d.	82	19	5
14 ft. 11 in. . . .	3″ York paving, in mortar	8½d.	0	10	6¾
284¾ yds. . . .	Backing, including levelling	5½d.	6	10	5½
319 ft. 1 in. . . .	Circular granite, scappel-dressed	2s. 6d.	39	17	8½
9 ft. 1 in.. . . .	Cragwell stone, scappel-dressed	1s. 10d.	0	17	6¼
2479 ft. 6 in. . .	Circular granite, set in mortar . . .	2s. 10d.	351	5	3
8 ft. 4 in. . . .	Setting only	4d.	0	2	9¼
1698 ft. 1 in. super.	Labour, beds, and joints	10d.	70	15	0¼
161 ft. 1 in. super. .	Do. do.	5½d.	3	13	9¾
89 ft. 4 in. . . .	Plain face	1s.	4	9	4
512 ft. 7 in. . . .	Labour, circular face	1s. 9d.	44	17	0¼
1153 ft. 6 in. . .	Sunk work	1s. 9d.	100	18	7½
79 ft. 9 in. . . .	Circular sunk work	1s. 10d.	7	6	2½
25 ft.	Do. do.	1s.	1	5	0
346 ft. 5 in. . . .	Circular moulded work	3s. 6d.	60	12	5½
23 ft. 9 in. super. .	Do. do.	1s. 8d.	1	19	7
66 ft. 11 in. super. .	Labour, plain face	6½d.	1	16	2¾
201 ft. 1 in. super. .	Circular, plain face	9d.	7	10	9¼
42 ft. 6 in. super. .	Circular splay to brick-work	3d.	0	10	7½
204 ft. 7 in. cube .	Cragwell stone in chimney caps, including hoisting	1s. 3d.	43	9	5¾
154	Arch joints	6½d.	4	3	5
2 cwt. 2 qr. 4 lbs. .	Cramping lead	2d.	2	7	4
No. 24	6″ cramps, labour	6d	0	12	0
	Total	. .	2728	1	0¼


Details of
CHIMNIES
A
B
C
D
Ground
Line
Side View
Fig. 1
Fig. 2
Fig. 3
Fig. 4
SCALE OF FEET

IX.—*Account of the Destruction of the Bridge at Carrick on Shannon by Gunpowder*, 1845. *By Lieut.-Colonel* HARRY JONES, *R. E.*

THE old bridge across the Shannon, at Carrick on Shannon, was erected about one hundred years ago, and was one of the most regular and best built upon the river (Plate XXII.): it consisted of eleven semicircular arches, of about 23 feet span, of rubble masonry, with dressed ashlar coins for the arches; there was a spandril wall of 18 inches in breadth running longitudinally through the bridge: the masonry was extremely good, the spandril wall being very difficult to cut through.

In the destruction of this bridge, as at Banagher and Athlone, the same precautions were necessary to be observed, by using the minimum quantity of powder, so as to prevent injury to the houses of the town at each end of the bridge, and, further, not to interrupt the passage of the public by the breaking down the temporary wooden bridge which had been erected by the contractor, the stays of which were actually resting against the earth on which one of the piers stood (Plate XXIII.) which were to be charged with powder: this, with other piers, had been laid dry by the contractor, to facilitate the operation of deepening the bed of the river, and was included within the space enclosed by the dams (*a*, *a*, *a*, Plate XXIII.)

The piers being only 25 feet long from the extremity of each cut-water, it was considered that one charge would be effectual for quiet demolition: accordingly, orders were given to sink a shaft in the roadway, so that the charge might be placed in the centre of the pier, both as regarded its length and breadth: the shaft in the fourth pier was 10 feet 6 inches deep, 3 feet broad, and 4 feet 6 inches long. these latter dimensions were much greater than would have been the case could regular miners, with proper tools, have been found. The men engaged on the work were common labourers, taken from the work nearest at hand. It required fourteen hours to sink the shaft to the depth of the level of the springing of the arch: there were two difficulties experienced; one, the

great tenacity of the puddle which had been used as filling over the arches: and the other, the particular good quality of the spandril wall which was found in sinking the shaft, and was necessarily obliged to be cut away, and which consumed a considerable time.

The charge was placed in two canvass bags, forming one mass: when laid in the chamber, a length of 14 feet of Bickford's fuze was carried up to the road-way, secured in a wooden case, or tube: six minutes elapsed before the explosion took place, the effect of which was, that the fifth arch, and greater part of the fourth pier and arch, were thrown down: by the removal of one or two stones, the standing portion of the arch came down; at all events it was so much shaken as not to have been in a state to be useful in any way, and must, under any circumstances, have been taken down before repairs to the bridge could have been effected.

The sixth pier having been prepared for demolition in a similar manner as the fourth, and the same difficulties experienced in regard to the materials to be cut through, the same time was consumed in the execution of the work, viz., fourteen hours: the position of the pier being more distant from the temporary bridge, and it having been found that the charge in the first experiment was scarcely sufficient, it was decided to increase it by 20 lbs., which was done, the powder lodged in the same manner, and the connecting fuze brought up in a casing as before: the charge when fired produced perfect demolition; but the same objection to a small charge was observable on this occasion as at Athlone, that in a shallow river, where the mass of material is merely thrown up, and falls into the space previously covered by the arch, it will, in all probability, form a passage across from pier to pier, by which infantry would soon be enabled to pass: had double the quantity of powder been employed, and which on Service would no doubt have been done, the object to be gained being to prevent an enemy passing, or at least delaying him for some time, the materials of the pier and arch would, from the effects of the greater quantity of powder, have been scattered to the winds, and the river would have continued to flow in its former course without being stopped by the rubbish and stones, which, in the present instance, had filled up the water-way of the arch.

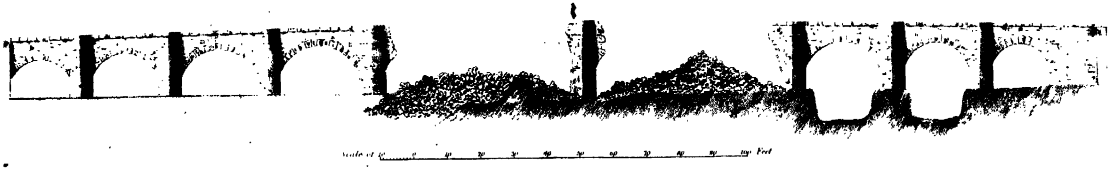
The tamping was the puddle and stones which had been taken out in sinking the shafts, carefully and firmly packed, and the top of this material covered with the ashlar coping of the parapet: one hour and three-quarters was occupied in tamping the first charge, and two hours for the second.

Carrick on Shannon Bridge.

Elevation of Bridge before its destruction

Elevation of Bridge after the first explosion

Elevation of Bridge after the second explosion

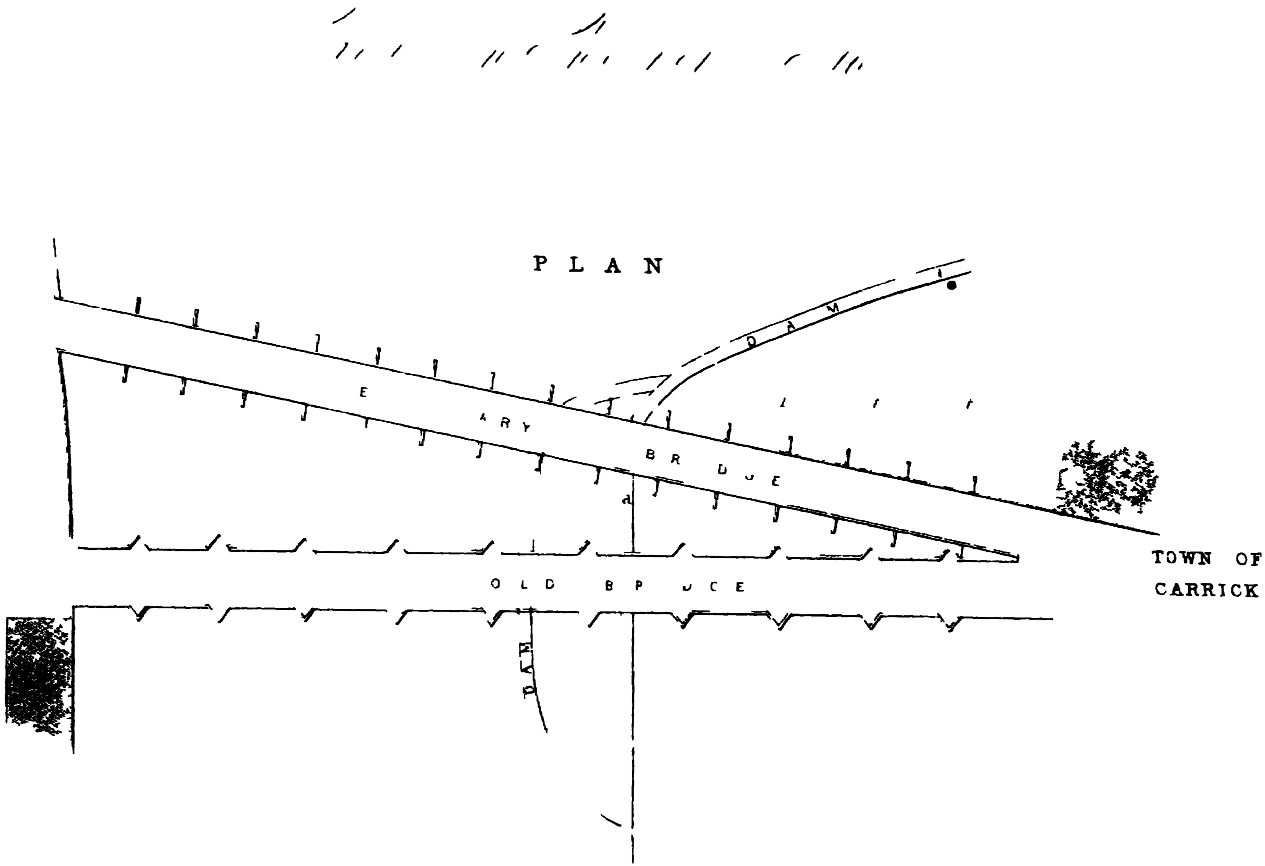


F. B. Cumberland del. R. R. Davies Sculp.

London, John Weale, Architectural Library, 59 High Holborn

Plate 23

PLAN



The charges calculated according to Major-General Pasley of the $\frac{LLR^3}{3}$ would have been totally inadequate: the charges used were, for the first 55 lbs., regulated by the quantities used at Athlone and Banagher: this, when exploded, having proved to be less than was necessary, and, moreover, the powder being that manufactured for blasting, the quantity for the second was increased by 20 lbs., making the second charge 75 lbs.: this, when exploded, produced perfect demolition, without scattering the materials in the slightest degree.

The time consumed in the operation of sinking the shaft to its proper depth was very great, but this was owing to the circumstance of the spandril wall being in the centre of the bridge: it was supposed that the effect of the explosion would be greater, and more efficient, when placed in one mass, than divided into two, by placing half the charge on each side of the wall. As there are still several arches of the bridge to be taken down, the experiment will be made by dividing the charge, which, if successful, will prove how much time will be saved, and which on Service, or in the Field, is a great object to be attained.

HARRY D. JONES,
Lieut.-Colonel, Royal Engineers.

Office of Public Works,
Dublin, 7th January, 1845.

X.—*Memorandum descriptive of the Alterations made in a Cast Iron Pump at the Jesuits' Barracks, Quebec, to enable it to resist the action of Frost. By Captain* STEHELIN, *R. E.*

A fire-engine manufacturer at Quebec has constructed two pumps which have resisted the effects of frost. I endeavoured to find out the principle of his pumps, in order to erect one of a similar construction at the Jesuits' Barracks; but finding that it was considered a secret, I caused the old pump to be altered according to the annexed plan (Plate XXIV.), and it has answered the purpose, resisting the action of frost when the thermometer was 26° below zero.

It is apparent from exterior inspection of the pumps before mentioned, that they have two working barrels; and it requires some strength to move the handle freely, which works like a pendulum at the side: in the one altered at the Jesuits' Barracks, the pump can be worked by a child.

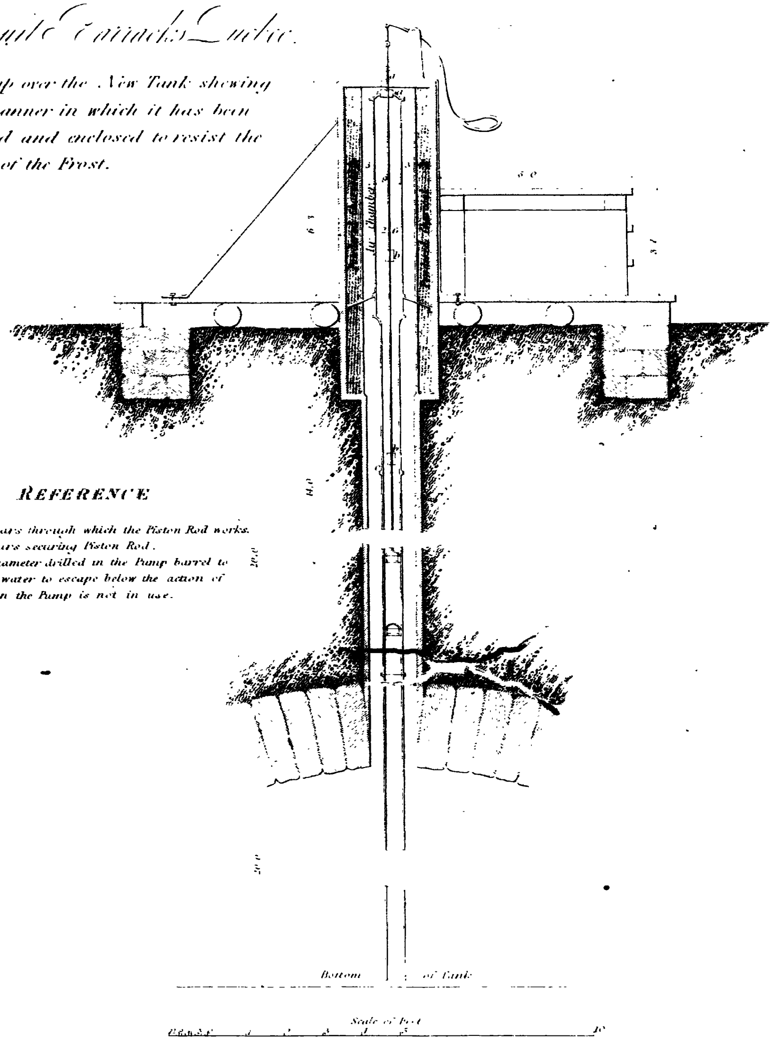
Two precautions were taken to prevent the frost affecting the water in the pump: first, a hole $\frac{3}{16}$ths of an inch in diameter was drilled 4 feet below the level of the ground, to permit the water to descend to that depth when the pump was not at work. Secondly, a chamber was formed round the pump, made tight to exclude the external air, and communicating directly with the well, so that the air in the chamber should always be of the same temperature as that in the tank. The first principle has been adopted in Canada with wooden pumps; but in those of cast iron, and in so severe a climate as Quebec, I think the air-box indispensable.

It is clear that the platform shown in the Plate will be unnecessary when the pump is expressly constructed for this country, as the shaft will only require to be the height of the delivering spout, and a proportionate saving of materials will be effected in all parts of the construction. I consider that the detaching of the handle from the body of the pump is a great advantage, as the latter is guarded from the violent concussions which take place in barrack pumps, and which, loosening the joints, cause them to be continually drawing air, and requiring repair.

B. S. STEHELIN,
Captain, R. E.

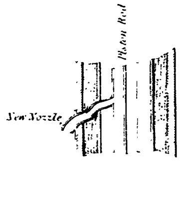
Jesuit Barracks Quebec.

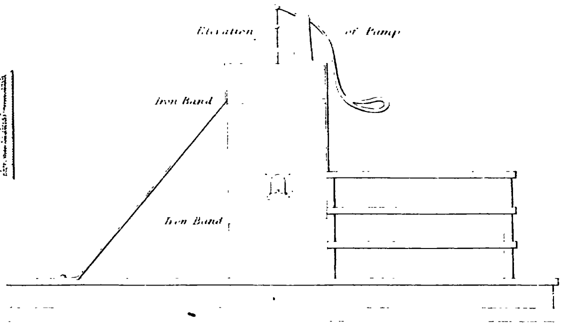
Pump over the New Tank shewing the manner in which it has been altered and enclosed to resist the effect of the Frost.



REFERENCE

a a Brass Collars through which the Piston Rod works.
b b Brass Collars securing Piston Rod.
c Holes 1/16 diameter drilled in the Pump barrel to allow the water to escape below the action of Frost when the Pump is not in use.

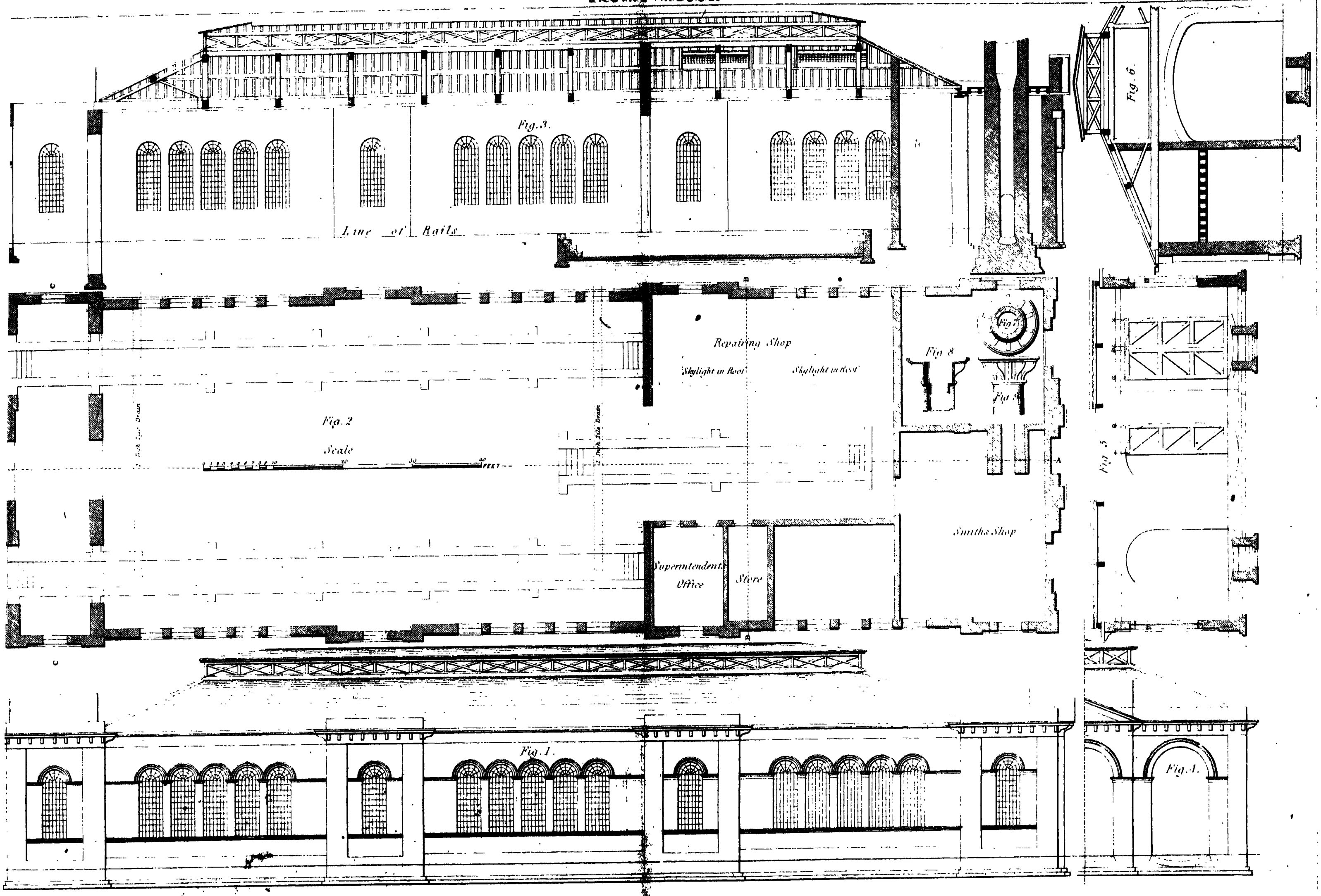




F W Cumberland del. B R Davies sc

London John Weale Architectural Library 59 High Holborn

ENGINE HOUSE.



J. S. Le Roux sc.

XI.—*The Taper Chain Tension Bridge at Ballee Khâl, near Calcutta, in its renewed Form, after the Failure in June,* 1845. *By Captain* Goodwyn, *E. I. C. Engineers.*

DETAIL OF THE CONSTRUCTION.

The span is 250 feet between the centres of the standards; width of platform 18 feet between the centres of the longitudinal beams, or 16 feet clear traffic-way inside the railing (*vide* Plate of Details, fig. 17). The height of the platform is 18 feet above ordinary, and 10 feet above extreme flood rise (*vide* Drawing of Elevation).

Chains.—The section of the chains at the point of suspension is 44·70 square inches, being each composed of fifteen rods of $1\frac{3}{8}$ inch diameter, and tapering thence to two rods in the centre (figs. 21, 22, of Details). The power of the chain at this point, therefore, is 402 tons, at 9 tons per square inch, and the greatest tension to which the chains can be subjected at that point is 338 tons, allowing the extreme weight of gravity of 120 ℔s. per square foot of area of platform. The weight of the bridge by itself, per square foot of platform, is 45 ℔s., and the greatest load that can be brought upon it is 70 ℔s. per square foot; there is therefore a surplus power of 64 tons at the upper point of the chain.

The action of the oblique suspending rods being auxiliary to that of the chain, these rods abstract a portion of the tension from each link in succession from the upper point; or rather, each link in succession *from the centre* becomes *nearly* a resultant force composed of the link and its oblique auxiliary immediately below it.[1] The section of iron therefore in each link is made to

[1] This is apparent from an accompanying diagram, showing the half curve of the chain, and on which is drawn in dotted lines the curve which would have been formed had each link been a *true* resultant of the two forces alluded to, and the whole in equilibrium, and to which the actual curve nearly approximates. The resultant links are obtained both in direction and magnitude from the known powers exerted on the component forces, and the angle subtended by them worked out both mathematically and from a scale of equal parts.

to cast boxes (fig. 17), which are let into stone blocks, and are immoveable: thus, though the fullest amount of probable tension at the centre is provided for by the section of iron there, the action of compression is also secured against by the above arrangement, and the ends of the planks abut against a stout beam let across the roadway into both piers.

HENRY GOODWYN.

Statement of the Proof to which the Ballee Khâl Bridge was publicly subjected on the 12th February, 1846.

1st. An ordinary traffic load of sixteen carts, eight starting from each end of the bridge, each cart containing 9 cwt., and drawn by a pair of bullocks.

2ndly. A 24-pounder gun carriage and timber, drawn slowly over by thirty-six bullocks; the weight being 78 cwt. on a length of platform of 9 feet, the distance between the axles. No deflection of the platform was visible during the transit of this weight. This load must have brought, including the weight of the bridge, 102 lbs. on every square foot of platform as it passed along.

3rdly. A crowd of natives, starting from both ends of the bridge, in as dense masses as they could be made to move: it was computed that 700 persons must have been on the bridge at the same time for full half an hour, and *all in motion*.

4thly. An elephant, weighing nearly 4 tons, walked over, which in motion must have exerted a power of at least 6 tons at every step; the length between the front and hind feet was 6′ 3″: thus his whole weight was on a space between the points of attachment of the oblique rods, and must have caused a load of at least 120 lbs. per square foot of platform, or a tension on the rods of full 9 tons per square inch of iron. A visible impression was made on the platform as he moved along, causing a deflection at each step of about 1 inch.

During the whole of these trials, and which tested the bridge to a greater degree than it is ever likely to be again, not a bolt moved, nor was a sound of friction heard: the whole fabric seemed under the dominion of tension, and the rods to be drawn fairly in the direction of their length. A slight undulation

was perceptible during the passage of the elephant, but it was of an easy yielding nature, and without causing undue strain on a single part.

The whole proof was witnessed by the Deputy-Governor of Bengal and the entire inhabitants of Calcutta and the neighbourhood.

HENRY GOODWYN.

Report of the Method adopted in Slinging and Fastening the several Chains, Rods, Beams, and other Iron-work of the new Tension Bridge, constructed by Captain Henry Goodwyn, E. I. C. Engineers, over the Ballee Khâl, near Calcutta.

As soon as the masonry standards had been built up to their proper height, preparations were made for raising and fixing the four large stone blocks or rests for the four cast iron saddles that support the tower-links of the chains: the object of these stones is to equalize the pressure throughout the piers on which they rest, and their size is $6' \times 4' \times 8''$.

Though it is intended in this Report to give only the method of slinging or raising the iron parts of the bridge, yet it is necessary, as the first step, to give a drawing and description of the manner in which the stones were fixed on the piers; as the cast iron saddles were hoisted, after the stones, by the same tackle and the same process exactly.

A large mast or derrick (A, fig. 1, Plate XXVI.) was hoisted up by ropes into the position seen in the drawing; the end resting upon a platform (D) of 4-inch teak planks, placed across the opening between the wing-walls (B B) in rear of the standard, and midway between their junction with the piers; and the planks rested upon the offsets of these walls.

This derrick (A) was kept in its upright position by several guy-ropes (*a a*) that were fastened to posts in the banks, or to trees close in the rear; all care being taken to insure it from slipping. About 10 feet above the top of the standard a large double block (E) with wooden sheaves was lashed to this derrick with stout rope above the teak cleat (*c*), which was securely nailed to it, and which could prevent any slipping of the rope which held the block, as seen in the small fig. 2. A rope was now very firmly bound round the stone to be raised, and to this a single block was attached, as in the small fig. 3, (*e* being the single block, which also had wooden sheaves.) The main rope to be hauled upon, after passing through both the blocks above named, was led to

the foot of the derrick, where it was taken through the snatch-block (*f*),—an iron one, with a brass sheaf,—and the fall carried to the rear, where the men were arranged to pull.

When all these arrangements were finished, the stone was gradually raised, and was hanging some few feet higher than the top of the tower: the guy-ropes from one side were now slackened a little, and the derrick was allowed to lean or sink slowly over the tower upon which the stone was to be fixed, until the suspended stone hung over its future site, as at *s s*, fig. 1. The main hauling rope was now let loose gradually, and the stone lowered.

In this way were the four tower stones all raised and lowered, one derrick and apparatus being required for each standard.

After these were fixed, the four cast iron saddles were raised and lowered in a similar manner, and by the same tackle. These saddles are dovetailed into the stones, and run with lead to fasten them securely.

The mast or derrick was about 50 feet long, 20 inches diameter at the foot, and 10 inches at the top: the wood, fir.

The rope made use of was 4-inch coil rope.

The mechanical power—one double block, one single block, and one snatch-block.

Back Chains.—After the tower-links had been put together and bolted in their proper position upon these saddles, the back retaining chains were commenced, (*vide* fig. 5.)

A sloping platform or framing of bamboos was strongly constructed, reaching from the blocks of retaining masonry (in which the ground-links had been securely moored, having a bearing against stones imbedded in the brick-work) to the top of the standards, on which to support the back chains in a straight line to the tower-bolts of the tower-links. Upon this framing the classes were enabled to put together the back chains, link by link, and to connect the whole to the rear bolts of the tower-links on both sides of the Khâl, without causing any strain upon them: care must always be taken that such is the case, else the stones and saddles will be displaced by the weight of the back chains not meeting with a strain or force to counteract it, until the main chains and platform be put up. Hence the necessity of constructing the framing, and allowing it to remain until the actual bridge be slung.

Fig. 5.—This framing was made of bamboos, and consisted of uprights

about 10 or 12 feet apart, resting on the offsets of the wing-walls, inside and outside; and some horizontals lashed to them at various heights, to support the links as they were completed; the men commencing from the retaining masonry, and bolting the links up to the tower-links successively.

To strengthen this framing, some long bamboos were also lashed to the uprights longitudinally, both outside and inside the wing-walls; and as the horizontals were not strong enough to bear the great weight of the chains, a few large fir or teak logs were placed beneath the links, and resting on the masonry of the wing-walls, at right angles to the line of the links themselves: these held up the chains, and were not removed until the main chains were slung.

There was a bamboo framing for each of the four back chains, which were completed by the 5th instant.

The back retaining rods or stays were bolted to the tower-bolts in rear of the tower-links, but only the upper halves; the lower halves were not coupled to them until the main chains had been slung.

The derrick used on each side to hoist the stones and saddles had been removed before the back chains had been commenced; but when the latter were completed, the two derricks were again hoisted (as will be mentioned immediately), and preparations made for slinging the

Main Chains.—Instead of making use of a service bridge, or a temporary assisting rope bridge, and putting the main chains together link by link, it was proposed in this instance to raise, if possible, one entire chain by means of ropes and blocks and a derrick, and from the north side of the bridge ONLY; and when bolted to the first main link from the north side, it should be allowed to fall into its curve at once.

The following arrangements were made on the 5th May, and reference must be had to the drawing (fig. 4).

The two derricks were hoisted first immediately behind the towers of the north standard, the foot of each resting upon the offsets of the wing-walls, just at the angle or corner, where they meet the footings of the piers. To secure them as firmly as possible, each was lashed (as seen in drawing) to the tower in its front, and was kept upright by guy-ropes, as before adopted.

A framing of bamboos was now constructed on the bund or coffer-dam in front of the south standard, reaching from the tower-links to low-water mark,

and a smaller framing similarly constructed in front of the north standard: this latter, however, had a small platform made about ten feet lower than the top of the standard (as seen in drawing).

Four native boats were moored in the stream by ropes stretched from bank to bank, in the line of the chains, and at some distance from each other; and a platform of teak planks was made, stretching from gunwale to gunwale, to the low-water mark of each bank (*vide* fig. 4).

The classes now commenced bolting together the links of each chain from the tower-links of the south standard, by means of the framing, upon which they put them together, until they arrived at the low-water mark, when they went on with the bolting upon the platform of the boats. The chains were allowed to hang down of their own weight, as seen in the figure, as far as the platform of the boats on which they afterwards were placed. They now left off bolting the links of the western chain, or the one that is farthest from the Hoogley, having completed about ten of each, and the eastern chain was continued. By 7 A.M. of the 6th instant, it was finished as shown in the figure: one or two of the last links attached were supported over the mud of the bund on the north side, upon the lower part of the bamboo framing before mentioned.

A description must now be given of the tackle used, how applied, with the power, and mode of fastening.

It will be first necessary to state that the two first main links, reckoning from the tower-links of the north standard, had been previously bolted to these links, and allowed to hang down upon the small platform marked P in the figure. The object was to raise the eastern chain, when all but the above link were bolted up to the platform P, where the classes waited to bolt it to the first main link, already described as resting upon the platform; and that connection once made, the chain was slung.

A large double block (*a*, fig. 4,) was lashed securely to the bolt which connects the first and second links, reckoning from the centre link towards the north side, by an iron chain: another (*b*, fig. 4,) was attached to the derrick A, as high as possible, to facilitate the hoisting, it being lashed above the cleat (*m*, fig. 4). The rope was taken through these blocks, and the fall through a snatch-block (*c*, fig. 4,) lashed to the foot of the derrick, and thence to the rear, where the men were arranged to pull.

A large treble block (*d*, fig. 4,) was fastened in a similar manner with a

chain to the bolt connecting the links Nos. 2 and 3 on the north side; and another treble block (*k*, fig. 4,) to the rear-bolt of tower-link (*s*, fig. 4). The rope, after passing through these blocks, was led along the eastern back chain through a snatch-block (*h*, fig. 4), lashed to the derrick over the cleat (*m*), and through another snatch-block which had been lashed to the back chain a little above the ground level in rear of the wing-walls (see fig. 6): the fall was then taken along the bank at a right angle, on account of there being but little open ground in rear of the retaining masonry.

There being no force in an opposite direction to the pull from the last-mentioned snatch-block upon the back chain, it was necessary to fasten a rope to the back chain, and make it quite taut to a tree on the opposite side of the chain, to counteract the great strain (fig. 6).

A small rope was tied to the link No. 2 from the north standard, for the men to pull it into position when near to the platform, (P, fig. 4, *r*.)

These arrangements being finished by 9 A.M. of the 6th instant, the Coolies began to haul on the ropes. A few minutes had elapsed, when the rope of the treble blocks gave way, and broke near the snatch-block (*vide* fig. 6,) fastened to the chain just above the ground level, and before the eastern main chain was at all raised from the platform on the boats. The edges of the snatch-block (which is of iron, with a brass sheaf) being sharp, must have cut the rope in its passage, the pull being at a right angle, (*vide* fig. 6.) It was now determined, after a new rope was rove and adjusted, that the men should pull directly to the rear, though much cramped in their moving through a small open place.

As there was a stopper on the rope from the tower-link, no accident ensued, and no other rope gave way. They now pulled to the rear, a few turns of the ropes being taken, after each pull, round some trees, to prevent any slipping.

In this manner was the chain raised sufficiently to allow the bolt which connects Links 1 and 2 to be inserted by the classes upon the platform about 2 P.M., the delay having been owing to the fracture of the rope in the morning. The eastern main chain was now allowed to sink until the catenary was gained, when the ropes and blocks were removed to the other derrick for the western chain.

The classes now returned to the bolting of the remaining links of the western chain, which was completed by 9 A.M. of the 7th instant.

The same tackle and mode of arrangement being made use of for this chain, as for the first, the men succeeded in hoisting it without any accident by 10 A.M., when the bolt that connects the almost entire chain to the first main link was inserted.

The rope was of 5-inch coir; and there were two double, two treble, and two snatch-blocks required; also two small iron chains.

Longitudinal Beams.—The bamboo scaffolding that supported the back chains was now removed; but the back chains, being heavier than the main chains, began to bend and curve; consequently it was necessary to leave the logs mentioned as being placed underneath in page 89, and to put a few more to support them until the platform was slung: this would offer a counteracting strain.

It had been proposed to sling the longitudinal beams and the platform in bays, each bay consisting of a pair of longitudinal and three transverse beams (one of the latter being a trussed beam), and to hoist each bay from a small platform formed on two of the boats moored under its proper place, beginning from the centre bay, and working towards the piers. The bays were, however, found to be too heavy to hoist and to handle easily. The classes therefore began now to put the longitudinal and oblique rods together, piece by piece; the platform was eventually formed in this manner: the men stood on the links of the chains, and either hauled up each piece from the boats, where others slung them, and then bolted or screwed them into position; or the men in the boats hauled up parts, such as the transverse beams, by single blocks lashed to the links above them, and held on to the ropes until the classes above had screwed them to the longitudinals. First, the longitudinals and oblique auxiliary rods which hold them by the sockets were all slung, beginning from the centre, and working both ways towards the piers: the cast iron sockets of course being previously riveted to the outward longitudinals, the oblique rods were put through them successively, and their upper ends secured to the chain-bolts. No internal longitudinals were put up until the outward beams were all fixed. The last pair of each of the latter, or the bay, nearest to each standard, was fixed in its place, when the pier was constructed; into which it enters, and is bolted to the large transverse iron bar, which, in the pier, unites the ends of all the longitudinals, outward and internal. This pair had been therefore built into the masonry, and then levelled. After the

classes had attached all the longitudinals, working from the centre to the piers, right and left, it was found that the second pair of outward longitudinals, (reckoning from the piers towards the centre,) overlapped by an inch or more the first pair that had been so long before built into the masonry of these piers: being evidently a little too long, they were left unattached, however, until the platform and iron railing had been fixed, so as to measure exactly the quantity to be cut off when the weight had brought down the whole bridge to the horizontal line.

The classes were employed all the 8th and 9th in slinging and fixing the outward longitudinals, with the oblique rods which hold them to the chains.

These beams, it was now found, formed a curve instead of a perfectly horizontal line, the one intended in this system of "Tension Bridges;" and this did not subside even after the adjustment wedges of the centre links were with some trouble knocked out from the loops, enabling the centre links to become a few inches longer.

It was, however, expected that when the whole weight of transverse beams, iron railing, platform, and metalling were put on, the bridge would assume the horizontal line. Not a longitudinal beam was cut until the transverse and other longitudinals, the internal ones, were all fitted, and the entire railing completed.

Until the 14th the classes endeavoured, as much as possible, to reduce the curve by screwing up the oblique rods, or loosening them wherever it seemed wanted.

The mode in which the men were able to knock out the adjustment wedges of the centre links was the following:

A treble block (Pl. XXVII. fig. 8) was first lashed with an iron chain to the bolt (B) at each end of the centre link; and the fall of the rope was led through the one nearest to the south standard; whence it was taken over the tower-links to the rear, where there was a direct pull from the bank. After some time, the strain of the chain being taken off, the wedges (W, W, fig. 8,) were knocked out with a hammer. The tackle being now slacked from the tree, around which several turns had been made, the chain fell some inches.

The classes were also employed on the 12th in adjusting the back stays on both sides of the Khâl. They were coupled together; but the main chains not being in tension, the stays were loose, and the cast iron plates, through which they pass, did not come up to the stone blocks, which are imbedded in

the masonry of the wing-walls, and against which they should have a bearing. These stones are fixed, or built in the masonry of small arches at the bottom of the wing-walls: in these the rods should pass through cast iron plates, and are secured by nuts which work on the threads of the screwed ends of the stays. One inch of the screwed ends below the nuts was left, and the space intervening between the iron and the curve of the arch bricked up, as seen in fig. 9. When the masonry became set, the stays became considerably taut as they were now screwed up.

As previously mentioned, two treble blocks (B, B, fig. 8,) were lashed to the bolts at each end of the centre links with iron chains. The fall (*f*, fig. 10,) passing through the arch of the north standard, was hauled taut; the block (*s*, fig. 10,) was now attached to it securely, and another double block (*s′*, fig. 10,) to a tree in the rear; the rope to be now hauled upon being in the direction P, fig. 10.

14th.—It was now determined to make the following trial upon one line of longitudinals, to find out if weight would eventually bring them to the horizontal line; if the platform would in the end be enough to reduce them from the curve. The classes were ordered to sling the transverse beams, by one end only, to the longitudinals of the chain that had not been altered from the first day, at something less than double the distance those beams would be fixed at when properly arranged for the platform, thus bringing on one chain the weight it was intended to bear, or nearly so.

They therefore lashed about thirty of the transverse beams, commencing from the centre towards either pier. It was then found that the desired result was obtained, viz., that the longitudinals were brought to the horizontal lines by these transverse beams, and that when the railing and platform came to be slung and fixed, a like satisfactory end would be arrived at. The beams were removed in the evening; a single block was lashed to the chain wherever a beam was to be suspended, and the ropes' ends hung over the boat in which they were lying. A man then attached one end to the transverse, and hauled it up to the longitudinal, and another with a small rope lashed the beam to the latter, and so all were suspended.

15th.—Seeing that the curve would be reduced in the end by the mere putting on of the platform, &c., it was ordered that the wedges of adjustment, five in number, which had been only a few days before driven out, should to-day be again inserted, to make the chains of the original length. The same blocks

and tackle were used as on the 13th. Both chains were finished by the evening.

Transverse Beams.—These were all put up and bolted, as well as the internal longitudinals, in three days.

They were taken from the bank into the two boats, which anchored themselves under the bays as they successively were finished, beginning from the centre towards each standard. Two blocks were lashed to chains; the ends of the two ropes were then let fall into the boats, and one end of each made fast to a transverse beam; the men then hauled it up from the boats by the other ends into its future position, where they were held till the classes above had inserted the bolts, through the beam boxes, which bind them to the outward longitudinals. The centre bay had been completed immediately after the chain had been slung on the 7th, and a bay at each end, next to that of which the longitudinals had been built into the piers, as before mentioned, from the very first, was left without transverse beams, as it was the bay of adjustment, and the longitudinals had to be cut.

It must here be noticed, that none of the screwed ends of either the oblique rods or transverse truss rods were made tight until the whole platform, with railing and beams, was put on: they were left moderately so; they were not to be touched till the whole was completed: then every nut was to be screwed firmly home, and the platform adjusted by such means to the true horizontal line.

Railing.—On the 20th this part of the bridge was commenced, and by the evening of the 24th all the stanchions, stays, diagonal braces, &c., were put up on all except the adjusting bays.

Taken from the banks into the two boats, they pulled them up to the platform, piece by piece, and each bay was completed by itself; that is, the stanchions, &c., were put up at the same time opposite to each other; that the transverse beams might be shifted *only once;* and that the bolts holding the beam boxes and stays of the stanchions might be well screwed up, and the diagonal braces made as stiff as possible; thereby making each bay as stiff and as firm as could be before its adjoining one was commenced. They worked as usual from the centre towards the piers.

The weight of the platform, and the weight of the mass of earth thrown on

to the lower links of the back chains, in order to fill up the cavity between the retaining blocks of masonry and the rear of the wing-walls, had now completely tightened the back chains. The logs that had been placed under them (fig. 5) were now removed, and the chains appeared straight and taut. The back stays were now finally adjusted, and the nuts screwed up as far as possible, the masonry having become well set.

Adjusting Bays.—The oblique rods often in these bridges happen to pass just over a beam box, to which a stay to a railing stanchion should be bolted. In such cases it is necessary to heat the stay at the forge, in order that it may be bent so as to pass clear of the oblique rod. The stay must be also lengthened at the same time by hammering it while hot, so that it may not only be bent, but also that it may have length enough to be attached to the stanchion without affecting its upright position by dragging.

Planking.—The teak planks were now laid down, in order to form the roadway. These are all put parallel to the lines of longitudinals, their length in the line of the bridge; each plank being secured to every transverse beam it crossed by two iron spikes passing through the table of the beam, through holes previously drilled or punched.

GEORGE SIM,

June, 1845. Lieutenant, Engineers.

Report of the Committee assembled to investigate the Cause of the Fall of the Ballee Khâl Bridge.

The Committee[1] that had been directed "to investigate the circumstances of the failure of the Ballee Khâl iron tension bridge, and to report on the expediency of re-constructing it on the same principle as before,"[2] having proceeded to its site, and carefully examined the suspending chains, drop-rods, road beams, castings, &c. (the *wrought iron* of which they learned from Captain Goodwyn had been proved in the bridge manufactory by a strain of 10 tons on

[1] Lieut.-Colonel E. Garstin, Superintending Engineer, L. Ps.; Lieut.-Colonel W. N. Forbes, Engineers, Mint Master; and Lieut.-Colonel A. Irvine, C.B., Engineers.

[2] Order, dated Fort William, 18th June, 1845.

the square inch), are of opinion that the "*disruption*" of the structure was not attributable to the *quality of the materials*, which, in so far as *it* could be judged of by inspection (or apart from re-testing), was good; nor to imperfection of workmanship, which, where admitting of survey, appeared unobjectionable.

2nd. The Committee have every reason to believe that the detail of the circumstances which preceded and accompanied the disruption of the bridge, have been correctly described by Captain Goodwyn,[3] as also that the cause which he has assigned *for it* was in reality the one to which it was attributable.

3rd. The Committee, having regard to the cause assigned by Captain Goodwyn for the failure of the bridge, viz., his having *virtually set free* the ends of the longitudinal roadway beams from their "holdfasts" in the abutments, and with reference to his proposal for re-constructing the bridge with nearly similar holdfasts, deemed it necessary to direct as much attention to the investigation of this important point as the emergency of the case would admit of; and the grounds on which they ultimately arrived at the conclusion, that he was neither mistaken as to the cause of failure, nor in error in proposing the adoption of a modified form of holdfasts in the renewed bridge, remain to be briefly brought to notice.

4th. There are four sorts of suspension bridges:

(1.) Those in which the planking of the roadway (excepting short platforms near the abutments) rests solely on the suspending chains, as is the case in some of the Chinese chain bridges, the bridge of *Penipé*, in South America, &c.

(2.) Those in which the roadway side-beams (carrying the planking, railing, &c.) are only connected with the main suspending chain by vertical rods, as in the *Menai*, and thousands of other bridges constructed on the plan patented by Sir Samuel Brown, formerly best known by the name of "Cable Brown."

(3.) Those in which the roadway is entirely supported by ropes, or chains, or wires, proceeding obliquely from the upper end of abutment posts or piers, as is the case in many of the primitive bridges formed of coir-rope, canes, bamboos, &c., met with in Asia and South America, and in some of the light-bar and iron wire bridges of Europe.

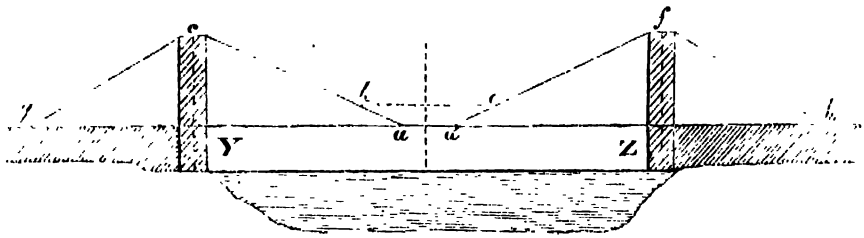
(4.) Those in which the roadway platform is partly supported by rods descending obliquely from the piers, partly by rods proceeding obliquely from the main suspending chains, and partly by the main suspending chains themselves; *which last*, diminishing in weight as they approach the middle of the

[3] *Vide* statement in Appendix.

span, are linked to the central portion of the roadway by short rods; *which last*, pointing outwards to the upper ends of the piers, have in reality the effect of making one of the main suspending chains nearly answer the purpose that would be effected by *two* separate chains, each of rather less than half its length, fastened to the upper ends of the piers,[4] and from *these* proceeding to the junctions of the central diverging rods with the roadway, and which interposing portion of roadway, with those adjacent to it, such chains would (if made strong enough) *serve to support;* this, too, without occasioning any tension on the part of the single main chain introduced (where it is employed) between the upper ends of the two central diverging links or rods; and as the bridge here—in general terms—described, is the one comparatively recently introduced by Mr. Dredge, and now in some degree in question, it becomes advisable to observe, that it partly embraces the principles of construction of the three classes of bridges previously mentioned, and here, under the heads of first, second, and third, referred to; nor, as much difference of opinion prevails with reference to the amount of strain borne by the central horizontal link of the main suspending chains, is it unimportant to observe that its amount may be made much, little, or *nothing*, by modes of construction appearing to the eye very nearly the same.

5th. Let Y Z, in the accompanying sketch, represent one of the outside horizontal roadway beams of a Dredge's bridge, and let this beam be, in the first instance, supposed inflexible, and only supported at the ends in a manner that would not subject it to central compression; it obviously could be made to support any additional load *besides its own weight* (*which* by means of its inflexibility is assumed to be already supported) by two strong chains (*a b c*, and *d e f*),

Fig. 1. *



[4] Reference to the '*back chains*,' constantly *employed* in rear of the abutments, is here and henceforth omitted.

* Mr. Weale, desirous of giving copies of this and the following diagrams in a more correct form, has deemed it advisable to have them engraved, from improved drawings, on Plate XXXI.

made fast in the usual manner behind the abutments (C Y, and Z *f*); and the central portion of roadway (*a d*) interposing between the ends of the chains (*a c* and *d f*), would, with these two chains, virtually form a catenarian curve (*c b a d e f*), very nearly coincident with that which would be formed by a single chain of nearly the same length suspended between the upper ends of the piers (*c* and *f*). The curve formed by the two chains (*a c*, and *d f*), and by the portion of roadway (*a d*), would, in fact, only vary from the curve formed by the single chain in consequence of the perfect horizontality of the inflexible portion of the roadway beam (*a d*); and although *theoretically* no portion of a catenarian curve can be a perfectly straight line, still in practice the lower central portion of a suspended chain of a bridge of any considerable span so nearly coincides with a straight line that the perfect catenarian curve ever falls solely within the depth of the rectangular iron bar forming the central portion of the longitudinal roadway beam. Now, seeing that under such circumstances the central portion of the roadway longitudinal beam (*a d*) virtually forms a portion of one of the main suspending chains, it is obvious that if this portion of the beam is made sufficiently strong, there would be no strain whatever on any horizontal cord line (*b e*) joining the points *b* and *e*, and drawn parallel to *a d*, at a distance that, on the full scale of a bridge, would represent 1½ or 2 feet. It will indeed further be seen, that under such circumstances the points *b* and *e* might (to use Mr. Dredge's own illustration) be joined by a "*packthread*," and that, independent of its own weight, *it* could not possibly be subjected to any strain by tension.

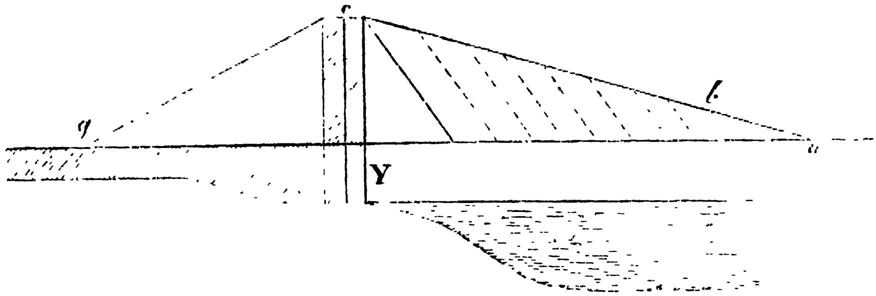
But although under such an arrangement no strain would be borne by the "packthread," it is sufficiently evident that a very considerable strain would be borne by the portion of the roadway beam (*a d*); in fact, nearly as great a strain as would have been borne by the packthread, had it formed a portion of the main suspending chain passing between the heads of the piers; and it hence becomes additionally evident that, as it is only by making use of the strength of the central portion of the roadway beam (*a d*), that the portion of the main suspending chain (*b e*) can be freed from tension,—it is essentially requisite that this central portion of the roadway beam should be *made strong* in the same ratio in which the portion of the main chain represented by the packthread *is made weak*.

6th. Were (it may be noted) the strength of the portion of roadway beam (*a d*) only sufficient to bear the weight of half the transverse breadth of the roadway platform of the length represented by *a d*, it would obviously be too

weak to have thrown upon it any of the work, or strain, of the main suspension chain; and it is clear that in the construction shown by the sketch, or where no strain would be thrown on the part of the main suspending chain represented by the packthread (*b e*), it would be essentially requisite that there should be ample strength, and rigidity, and inflexibility in the longitudinal beam; as, also, that were the roadway beam (Y Z) not perfectly inflexible throughout, it would be necessary to give such strength to the chains (*c a* and *d f*), and to the portion of roadway beam (*a d*), as would enable *c b a d e f*, regarded as one chain of uniform section and strength, to bear the tension of the weight of this chain itself, and that incident to the greatest central or other load that could at any time be brought on the roadway platform of a structure so supported.

7th. Here referring with a view to simplicity to another sketch in which only the half roadway beam, and the half main chain, need at first be represented, it will be seen that half the assumed inflexible roadway longitudinal

Fig. 2.

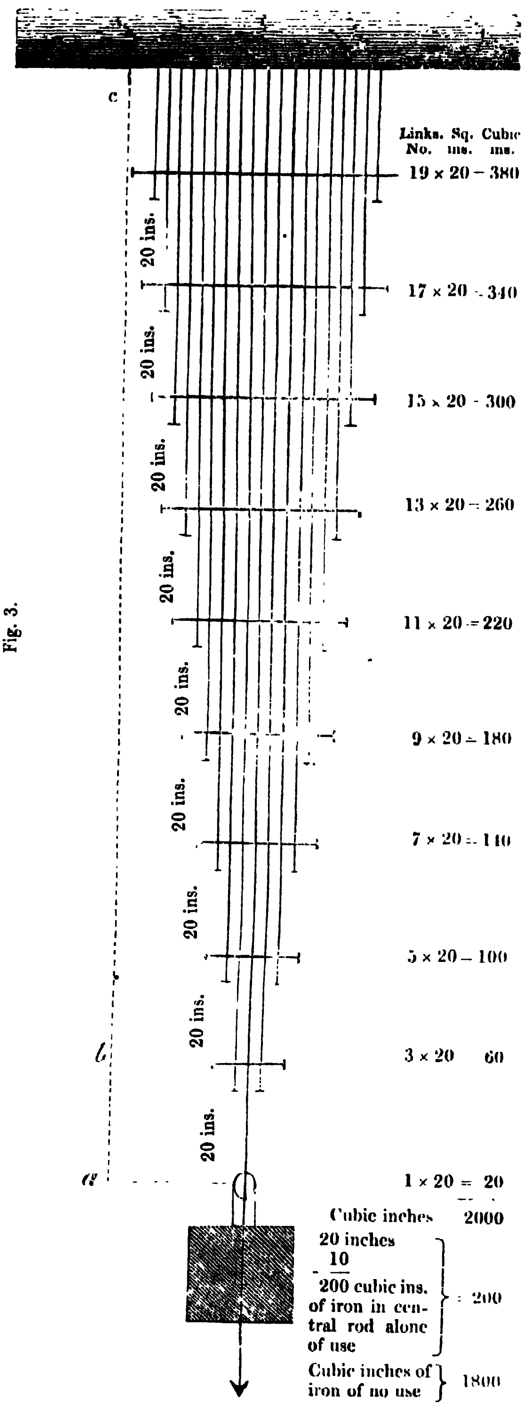


beam (Y *a*), and any load laid on it, would have wholly to be borne by the half main chain (*c b a*), whatever might be the additional number of oblique rods (represented in the sketch by dotted lines) intermediately introduced. It will in fact further be perceived, that as the total fabric projecting from the pier (c Y) would, in reality, form a "*truss*," of which (by the supposition reasoned on) the base beam (Y *a*) is inflexible (therefore requiring no intermediate support), the weight of the supplemental rods, fastened at the upper ends to the hypothenusal chain and at the lower ends to this beam, would only have the effect of increasing by their weight the *concavity* of the chain, and thereby *that* of rather weakening than strengthening the mechanical combination.

8th. Neither, as in such a combination the greatest strain would fall on the

outermost portion of the half main chain ($b\ a$,)—more especially when the chief portion of the load was placed on the roadway beam adjacent to a,—would any *additional strength* be gained by making any portion of the sectional area of the half main chain, *near the abutment*, *greater* than it was in the more remote portion of the chain ($b\ a$); for seeing that with reference to the assumed inflexibility of the roadway beam, the dotted oblique drop-rods are, from their weight, worse than useless, it is obvious that this unnecessary weight would only be still further added to by increasing the section of iron in the *half main chain* as it approached the abutment, (as *is admitted* in page 56 of the work published by Mr. Dredge in conjunction with Mr. Turnbull.) Supposing, for instance, that the chain ($c\ b\ a$) were formed in the manner represented in the accompanying sketch, figure 3, by a series of wrought iron rods, connected at equal distances with a set of transverse bolts, and that at each bolt from the upper or abutment end (c), the outer pair of rods were dispensed with, until, near the lower end (b), only a single rod (say of an inch square section) remained, it is certain that if such a chain were suspended VERTICALLY from

Fig. 3.



the transverse beam of a gibbet made strong enough to bear many times the utmost strain that could be brought on the chain without breaking it,—and that if, while so suspended, weights were attached to the lower end (*a*) of the chain,—the total amount of these weights could not exceed that which would break the lowest or single rod (*a b*); and it further is evident that this single or lower rod has its strength in no way added to by the comparatively immense quantity of iron in the upper portion of the compound chain, or with the exception of the central rod, situated between the points *b* and *c*.

It will indeed be seen, that if the distance between the transverse bolts of such a chain were 20 inches, and the upper set of *rods* were 19 in number, while at the lower end there was only *one*, there would be between the bolts ten lengths of 20 inches each of iron, and that if the section of each rod was (like that of the lower one) one inch square, the total number of cubic inches of iron in the chain (without including the iron in the bolts) would be 2000 cubic inches; and it will also be seen, that as out of this amount only the central rod, containing 200 cubic inches of metal, would be effective to resist the downward strain of the weights, the remaining 1800 cubic inches of iron would be utterly useless. By dividing the total number of cubic inches, 2000, by 200 inches, the length of the central rod, it may, moreover, be noted, that out of the same quantity of material a chain having a uniform section of 10 inches and the length 200 inches, might be formed, and that while the first or tapering chain would only be able to support a strain of 27 tons, the last, or chain with the same cubic contents and length, but with a uniform section, could only be broken by a weight of 270 tons.[5]

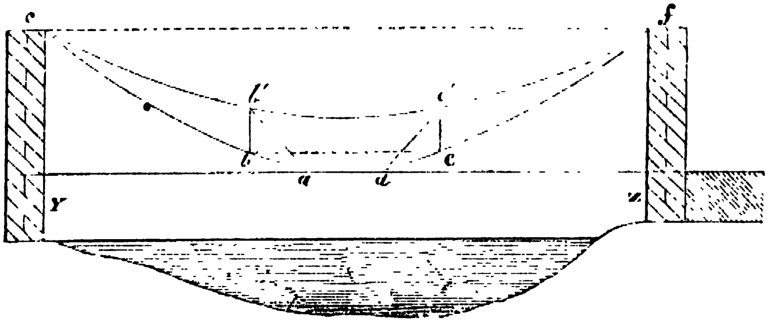
Here, bearing in mind the weakness of the taper chain to resist a vertical strain, or strain in the direction of its length, it will yet more clearly be perceived that when such a chain is employed comparatively horizontally, or in the situation shown in figs. 1 and 2, by *c b a*, its weakness at the lower rod, or between *a* and *b*, will be still further increased by the superfluous load of iron introduced between *b* and *c*, in the manner explained by fig. 3.

9th. Premising that although the facts here brought to notice have APPARENTLY a tendency to prove that the taper chain principle adopted by Mr. Dredge is not the best application of a given quantity of iron; it will ultimately be shown that in the mode of bridge construction practised by him, the whole quantity of material employed is turned to useful (although perhaps

[5] 27 tons × 10 square inches of section equal 270 tons.

not to the most useful) account; and having hitherto considered but the conditions incident to a main suspension chain having in reality no strain by tension on the portion of it represented by the packthread, or by the dotted line *b e*, in fig. 1, it now becomes advisable to regard the circumstances under which the utmost possible strain would be thrown on this portion of the main chain.

Fig. 4.



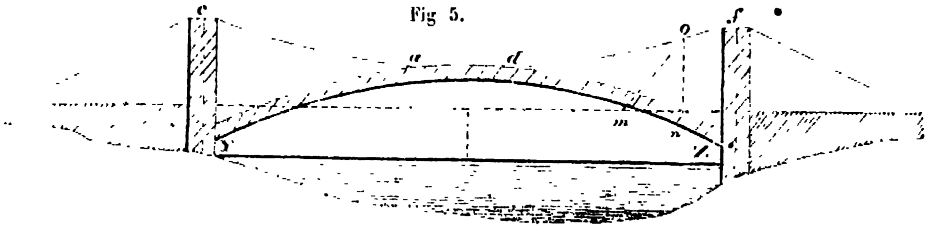
Were it possible, by any force applied to the ends of a *heavy chain* suspended between distant piers, to draw *it* horizontally into a perfectly straight line, it is obvious that the tension on its central portion would then *be a maximum;* also, that a chain so stretched would be in the worst possible condition for giving support to a load attached either to its central portion or any other part of it: it also is evident that the nearer the curve of the chain is made to approach a straight line, the greater will be the strain to which it is subjected, either by its own weight or by any additional load attached to it.

Now with these universally admitted facts in remembrance, let fig. 4 be referred to, where, as before, Y Z represents the roadway beam, and *c b a d e f*, the main suspending chain shown in fig. 1; and let this chain be supposed drawn up into the upper curve (*c b′ e′ f*), in which *b′ e′* represents a portion of this chain equal in length to the packthread line (*b e*) of the lower chain, and in which the link (*b′ a*) would come in place of the link (or portion of the chain) *b a* of the lower chain; and by inspection of the figure it will be seen, that as the upper chain is now much nearer to the horizontal line (*c f*), the tension at the central point between *b′* and *e′* would be greater than the tension at the central point between *a* and *d*; and this in a ratio known to be INVERSE to the deflection (or central drop) of the *lower* and *upper* chains: and having thus seen that the tension on the central portion of the upper chain (*b′ e′*) is greater than that on the central portion of the lower chain, or portion of the roadway beam

($a\ d$), it will also be perceived that the tension on this portion of roadway beam ($a\ d$), supposing it now to be solely supported by the upper chain, will be DECREASED in some ratio bearing direct proportion to the increase of the angle ($b'\ a$ Y); and further, that when the drop-rod ($b'\ a$) becomes vertical, the strain by tension will be totally removed from the *central portion of roadway beam* ($a\ d$), and therefore be wholly transferred to the upper suspending chain, and mainly to the central portion of it ($b'\ e'$). It will, moreover, be seen that the strain by tension on the central point of the roadway beam ($a\ d$) will BE GREATEST when the angle ($b\ a$ Y) IS LEAST; that is, when $b\ a$ is virtually made a portion of the main suspending chain, of which the portion of roadway beam ($a\ d$) constitutes another part, or when the structure is on one side of the roadway, solely supported by the lower main suspending chain ($c\ b\ a\ d\ e\ f$).

10th. Were the roadway BEAM MADE totally inflexible, *or were it acted on by compression at the abutment ends*, as it would be *if it were* made *fast at these ends*,—and if (with a sufficient sectional area) it were curved upwards into the form of an arch,— it is perfectly certain that no strain whatever, in the way of tension, could be brought upon IT by a main suspension chain attached near its central portion, or near that part of it which, in a bridge acting solely by compression—as for instance in a stone bridge—would form its "Keying." Supposing, for instance, the roadway beam to be arched into the form represented in the sketch, fig. 5, and that bearing firmly on the abutments at Y and

Fig 5.

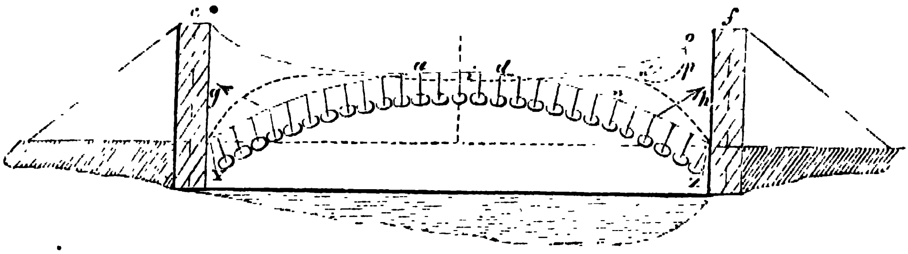


Z, it has sufficient sectional area to support itself, and any load laid on it, solely by compression, or without aid from the main suspending chain ($c\ a\ d\ f$), nothing can be more clear than that there would be no tension whatever on the portion of the chain ($a\ d$) if it were made fast (as shown in the sketch) to the "Keying" ($a\ d$) of the arch (Y $a\ d$ Z): it moreover is evident that any number of drop-rods, either oblique ones, as $o\ m$, or vertical ones, as $o\ n$, might then be introduced without their doing either good or harm, inasmuch as by the hypothesis reasoned on, the arch is in itself strong enough without them. The case, however, will be seen to be essentially different if the roadway beam,

or arch, is assumed to be (as *is*, in practice, the fact) not strong enough to support itself apart from the aid afforded by the main suspending chain and drop-rods.

Under the conditions last alluded to, it is known that if a long bar of iron, *laterally supported*, is formed into a circular curve, or arch, between two abutments, and is then uniformly loaded from end to end—the curve it will assume becomes similar to that represented by the dotted line (Y *g i h* Z) in the annexed fig. 6, by which it also will be seen that, with a view to sup-

Fig. 6.

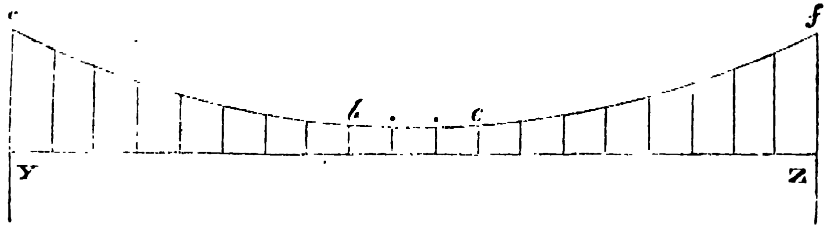


porting the crown of the *arch* (*a d*), and thereby keeping it nearly up to its original form, that of a segment of a circle, a main suspending chain (*c a d f*) might be very beneficially employed. But *if*, for the purpose of leaving part of the work of supporting the curved beam, or arch, to be effected by the drop-rods, the main suspending chain were not drawn sufficiently tight to give entire support to the crown of the arch,—it becomes important to observe that, as the bent beam, or arch, when uniformly loaded would still remain, in some degree, depressed at the crown (*a d*), it would still have a tendency to rise at the haunches (*g* and *h*), as shown by the dotted curve; and that, under such circumstances, no additional support whatever could be given by drop-rods, such as *n o*, inasmuch as the upward spring of the haunch of the arch would still have a tendency to slack or curve upward the drop-rod into the useless form indicated by the dotted line (*n′ p o*). And although, on the grounds here stated, Mr. Dredge is apparently warranted in arriving at the conclusion that the side roadway beams ought not to be curved, but to be horizontal, the facts above adverted to will, it is believed, serve fully to prove, that *by curving and stiffening the roadway beam, and by making it firmly rest on the abutments*, either *all* or *much* of the strain by tension on the central portion of the main suspending chain (*a b*) may be done away with,—and having thus (partly by fig. 1, and partly by figs. 5

and 6) shown that either by making a strong central portion of the roadway beam a portion of the main suspension chain, or by curving the roadway beam (thereby making it act by compression), much or all of the strain by tension may be removed from the central portion of the main suspending chain, or from a horizontal bar, or link, or "packthread," answering to *b e*, in fig. 1,—it now remains to be considered whether this object, or that of relieving the central and weakest portion of a gradually diminishing main suspending chain from tension can be efficiently effected *without giving the ends* of the longitudinal roadway beams firm and substantial support (*such as would be given by "holdfasts"*) *on and in* the abutments.

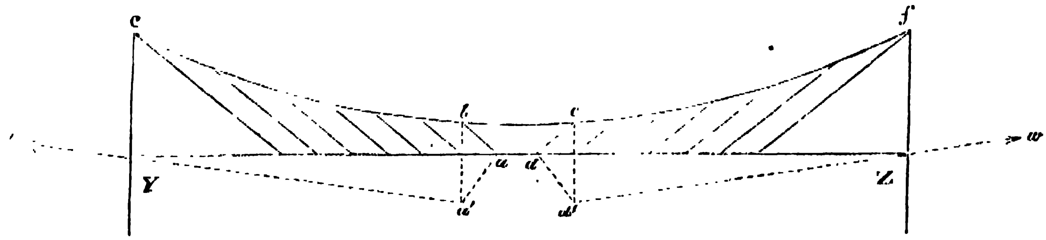
11th. A bar of iron 250 feet long, 5 inches deep, and $\frac{3}{4}$ of an inch thick (or such a one as we find Mr. Dredge considered of ample strength for the side longitudinal roadway beams of the Ballee Khâl Bridge), if set "entirely free at the ends," and if left unaided towards the centre and at other portions of its length by drop-rods connected with a main suspending chain, would certainly at once assume the form of a catenarian curve; and having done so, slip from off the abutments into the water. But supposing such a bar or beam to be intermediately carried by *drop-rods*, it is easily proved that *when these are vertical*, holdfasts at the ends of the beams in the abutments may be far more safely dispensed with than when, as in Mr. Dredge's construction, the drop-rods are oblique both to the main suspending chain and to the horizontal roadway beam. In fig. 7, where the drop-rods are represented as descending *vertically* from the

Fig. 7.



main suspending chain, a roadway beam, such as Y Z, might be cut into several pieces; and if each of these had two drop-rods connected with it, the respective pieces would still remain in a line nearly horizontal; but were the horizontal beam represented in fig. 8 as supported by oblique rods, to be cut across near its centre, the weight of each portion of the divided beam would immediately bring the central oblique rods (*b a* and *e d*) into the vertical positions (*b a′* and *e d′*), and at the same time the abutment ends of the beam, IF FREE, would fly

Fig. 8.



out in the directions Y *q* and Z *w*; and this in such a manner as when the roadway beam was heavily loaded would probably always (as in the case of the failure of the Ballee Khâl Bridge) serve to rend asunder the central horizontal link (*b e*), or the packthread portion, of the main suspending chain (*c b e f*, see fig. 8); and as the certainty of such an effect being produced by such a cause would obviously be in direct proportion to the weakness of the central portion of the main chain (*b e*), we cannot but conclude that Captain Goodwyn has good grounds for adopting a mode of construction giving to this central or horizontal portion of the main chain a much greater sectional area, therefore strength, than Mr. Dredge appears to consider requisite. It cannot indeed fail to be observed, that where there is no strain by tension on the portion of the chain (*b e*), (see figs. 1 and 8,) or where by the mode of construction adopted, the strain that would have been borne by it has been transferred to the central portion of the roadway beam (*a d*), cutting across this (*a d*) portion of this beam would invariably be a certain method of insuring the destruction of the bridge; yet *noting* that, in reality, Mr. Dredge's mode of construction does not wholly transfer the strain by tension on the central portion (*b e*) of the main chain to the central portion of the roadway beam (*a d*), it becomes still more certain that very considerable strength (consequently sectional area) ought to be given to the central portion (*b e*) of the main chain; and having in view the possibility of the failure of the central part of the roadway beams (*a d*) from various causes (besides that which led to it in the case of the Ballee Khâl Bridge), we confess we are inclined to believe that it would be practically expedient to give in all cases such strength to the central portion of the main chain (*b e*), as would enable it to support the structure in the event of the fracture of the central part of the roadway beam (*a d*).

12th. But, for the purpose of preventing such a fracture of the outside road-

way beams, and for the considerations stated, as also with a view to enabling the roadway beams to be trussed in the strongest possible manner by the roadway railing, and possibly by the two parallel iron bars running under the transverse roadway beams from end to end of the roadway (a position in which the iron in them is comparatively of little use), we are of opinion that abutment holdfasts for these outside roadway beams ought (as recommended by Captain Goodwyn) to be employed.

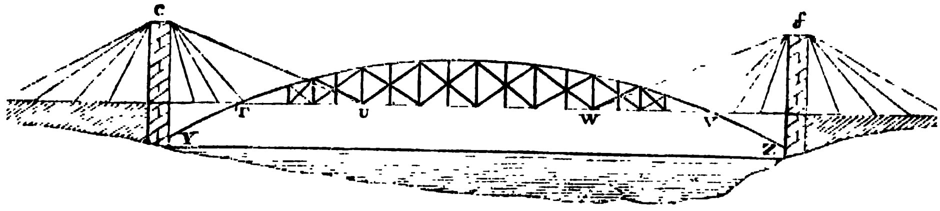
13th. As all other parties who have considered Mr. Dredge's mode of bridge construction agree with him in thinking that its strength most especially depends on the firmness and rigidity *given to the roadway*, which again obviously mainly depends on the strength given to the outside longitudinal roadway beams, it is undoubtedly advisable that these (more particularly when run across the stream horizontally) should, in addition to being securely trussed, have *in themselves* very considerable strength or sectional area; and on these grounds we entirely approve of the increase of their dimensions proposed by Captain Goodwyn for the new bridge.

14th. In such a bridge, the drop-rods are apparently made to pass obliquely between the main suspending chain and the horizontal roadway beams, for the purpose of making the strain by tension brought on the *drop-rods*—regarded as portions of supplemental suspending chains—act more nearly in the direction of their lengths; which, virtually, only is effected by making the portion of the roadway, interposing between any two pair of drop-rods, equally distant from the abutments *also*, partly serve as a portion of a main suspension chain; and assuming that by the construction described, the strength of the portion of outside roadway beam interposing between the lower ends of a pair of obliquely descending rods is—with the strength of these rods—fairly brought into action, as an auxiliary main suspending chain, it will clearly be perceived, that there would then not be such a necessity for having great sectional strength in the intermediate or central portion of the main, or upper suspending chain, as, apart from such an arrangement, would be indispensable.

15th. That no inconsiderable degree of relief may *be* given to the main or upper suspension chain by drop-rods so disposed, and by the agency of the interposing portions of roadway, may be proved by the following considerations:

Let it be supposed that in fig. 9, Y Z represents one of the outside longitudinal roadway beams of a suspension bridge, of which the portions Y T and

Fig. 9.



Z V are supported by three chains C T, &c., and *f* V, &c., passing directly from the heads of these piers to these portions of the roadway (as was the case in the Ballee Khâl Bridge); it will be seen that if these six chains were made strong enough, or that even if the outside ones (C T and *f* V) were made strong enough, these, *and a properly trussed portion of intermediate roadway beam* (T V), (or portion of beam so trussed that it could not be sagged or bent downwards by any load of carriage, or other load, proposed to be borne by it), might alone be made to constitute the support of the structure; and it will then also be seen that, so formed, the chains (C T and *f* V) and the interposing portion of trussed roadway beam (V T) would virtually form a main suspending chain, and which would only be prevented from assuming the catenarian form by the inflexibility of the trussed portion of roadway (V T). But in a bridge of large span, the stability of such a structure would obviously be materially increased by the introduction of other oblique rods, or chains, descending from the heads of the piers, such as are represented by the lines C U and *f* W, which again will, with the interposing trussed portion of roadway beam (U W), form a second or auxiliary suspension chain; and by employing a sufficient number of such chains descending directly from the heads of the piers to the trussed roadway beam (as is the sole principle of construction in the 3rd class of suspension bridges described in paragraph 4th), it is known that bridges of 260 feet span may be, and have been, efficiently constructed; but also, that for spans of very considerable extent, the difficulty of equalizing the tension on the central or longest descending chains (more especially where the roadway beams have been left without trussing, and where the chains have not been so united as to afford mutual support), renders the structure, in heavy storms of wind, liable to injurious vibration.

16th. Now noting that in bridges constructed on Mr. Dredge's plan successive portions of the main suspending chain (say in the first instance those adjacent to the heads of the piers) and the oblique rods descending from the

outside ends of the portions of main suspending chain virtually come in place of the rods C U and *f* W, shown in fig. 9, as directly descending from the heads of the piers, we at length arrive at a reason for a greater strength or a greater section of iron being given to the portions of main suspending chain adjoining the abutments, as also for in some degree diminishing the section of iron in the main chains as they approach the centre of the span.

And the simplest practical explanation of the conditions involved possibly resolves itself into this —that in proportion as strength, or section of iron, is dispensed with in the central portion of the main suspending chains, the comparatively great additional strength given to the roadway side beams renders them—in conjunction with the oblique drop-rods—available as supplemental suspending chains ; consequently in a manner that leaves it unnecessary to have such a quantity of material in the main or upper suspension chains, or in the entire structure, as, apart from such arrangements, would be requisite.

17th. Bearing further in mind that in suspension bridges of considerable span, the lower portion of the catenarian curve formed by one of the main suspending chains very nearly coincides with the horizontal line of the roadway platform, it is obvious that the roadway planking or platform might (as in some of the Chinese bridges[6] and in the bridge of Peñipé,) be directly laid on this lower (or nearly horizontal) portion of the main suspending chains, in a manner that, at this part of the structure, would render both the side beams of the roadway *platform*, and much of the material employed in it when separately suspended, unnecessary ; and although such a mode of construction is objectionable from the jar given to the fabric by heavy wheeled carriages descending the partly curved roadway platform, it can, by reference to the principle alluded to, be understood that where (as in Dredge's bridge) the side roadway beams are placed horizontally, and aided by oblique drop-rods made virtually to do part of the work of main suspending chains, a *less total quantity* of material may be employed, than where additional strength or weight has to be given to the main suspending chains, to enable them to support the necessarily greater weight of materials employed in a roadway of platform *separately framed*, and suspended by vertical drop-rods not in any way answering, as do the oblique ones, the purpose *of supplemental suspending chains*.

18th. The above illustration is offered with a view to reconciling the experi-

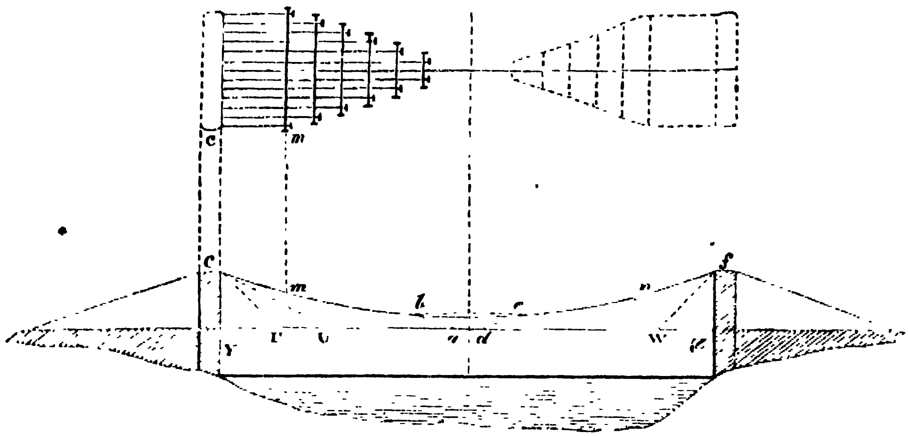
[6] See paragraph 4th.

mentally ascertained fact of the greater lightness of oblique-rodded bridges with the unquestionable truth, that, if precisely as much additional weight of material was given to the side roadway longitudinal beams as was dispensed with in the main suspending chains, the total weight of the structure would still remain the same. And as such an impression is deepened by regard to the consideration, that in suspension bridges formed with vertical drop-rods, side roadway longitudinal *iron beams* are not required, and in consequence are not introduced, it is necessary to observe, that it has previously been shown that in oblique-rodded bridges, the side longitudinal roadway beams *also* serve in no inconsiderable degree as portions of suspending chains, and that, ultimately, grounds will be adduced for believing that in such bridges the diminution of weight is effected by giving *one excess of strength* (or additional weight of materials) to the roadway beams, and not *two such provisions of it*, as would have been requisite had the *duties of road bearing*, and of suspension, been kept entirely separate; and when it is borne in remembrance that in *all* suspension bridges there is a tendency in the wrought iron materials to tear themselves to pieces by their own weight, and that in consequence a great excess of strength has to be given to counteract this evil, it will be perceived that, by making *one part* of the structure do the work (say) of TWO, there could not but be a total saving of weight by giving it only *one* (in *place of double*) *excess of strength*.

19th. Although the main object contemplated by the sort of bridge last adverted to, is excluding all material save such as directly contributes to the strength of the structure, we confess our inability to perceive strict attention to this principle in the arrangement of some of the oblique drop-rods, more especially of those descending from the main suspending chain in the vicinity of the heads of the piers.

In fig. 10, let *c m b e n f* represent a "Dredge's" suspending chain, and the letter *m* the point from which the first oblique drop-rod (*m* U) descends from the main suspending chain, it will be perceived that if *one* rod (*c* U) were employed by the same section of iron as either the outside rod of the main suspending chain (*c m*) or the drop-rod (*m* U), (which have equal sections,) there would necessarily be less iron in *c* U, than there is in *c m* and *m* U added together; inasmuch as *c* U, one side of the triangle (*c m* U), could not but be less in length than *c m* and *m* U, the other two sides of the same triangle, added together. And with the rod (*c* U) directly descending from the

Fig. 10.—Ground Plan.

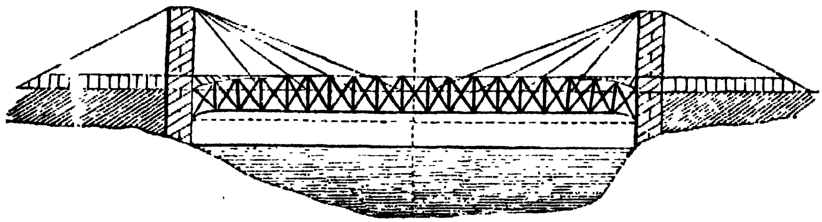


head of the pier (*c*), it will also be perceived that the strain brought by any load placed on the roadway side beams, and transferred by it to the point U, would be immediately communicated to the head of the pier, where it would be counteracted by the corresponding back chain, in a manner that would entirely remove from the main *suspending chain* the tension brought on it at the point *m* by the drop-rod (*m* U).

By the arrangement adverted to, the *main suspending chain* (*c m b e n f*) would not merely be relieved from the tension brought on it by the *drop-rod* (*m* U), but also from its weight, and from the weight of the main chain side rod (*c m*), (see ground plan sketch;) and as these two weights, added to those of several of the sets of drop-rods, with their corresponding rods forming the two outer sides of the main suspending chains situated nearest to the piers, have no inconsiderable tendency to render the main suspending chains more *concave* near the piers, therefore *more horizontal*, and *weaker at the central portion of the span*, there assuredly *is* reason to believe that the structure would be stronger if a greater number of drop-rods *near the piers were made to descend directly from the saddles placed on their heads.*

20th. Leaving the upper roadway beam and the roadway itself horizontal, the rigidity of the roadway, on which the strength of the fabric mainly depends, would certainly be increased if the material employed in the four longitudinal roadway beams were formed into *two beams*, and if the lower *one*, curved into a circular segment, was made to approach the upper or horizontal one towards the centre of the span, in the manner represented by fig. 11; and, were such a plan adopted, *the iron and materials of the roadway railings might be so dis-*

Fig. 11.



posed, as, in *conjunction with the beams described, to form continuous trusses between the abutments*, each truss probably nearly in itself of sufficient strength to bear its own weight (but assuredly no additional load) *without the intervention of any suspending chains.*

To side roadway trusses thus formed the suspending chains could be attached in a manner that, in conjunction with the drop-rods, would still leave the material employed in the *side beams, or trusses*, fully available for the purpose of intermediate portions of suspending chains; but as it has repeatedly been stated that we conceive the principle involved in such structures *is employing strength, or section of iron, given to the roadway side beams, or trusses, in place of strength, or section of iron, dispensed with in the main suspending chains*,—a conclusion that inevitably indicates the necessity for giving *greater strength* or section of iron to the *central portions* of these beams, *where, from the diminution of it in the main suspending chains, it is most indispensable*,- it requires further to be observed that the mode of trussing proposed would in reality provide the strength *there admitted to be most requisite.*

21st. Having alluded to such a mode of construction merely for the purpose of illustrating the conclusions arrived at with reference to the sort of bridge immediately under consideration, and consequently *not with any intention of giving a plan of a structure that could be employed in place of it,—a proceeding that would only be warrantable after numerous and extensive experiments have been undertaken and completed,*—we deem it necessary to bring distinctly to notice our entire acquiescence in the opinion expressed by Captain Goodwyn, and acted on in the bridges fitted up by him, in most other respects on Mr. Dredge's plan,—that GENERALLY *greater* strength, or *section of iron, should be given to their component parts than Mr. Dredge himself considers requisite.*

In other sorts of suspension bridges, the best Engineers have never ventured to subject *a square inch of iron* to a greater strain by tension than nine tons; and this, inasmuch as, although not actually fractured by an average load of less

than twenty-seven tons, *it begins to stretch when subjected to a strain exceeding ten tons.* Mr. Dredge, on the contrary, appears to have no hesitation in making an inch square bar take its chance under an occasional,[7] if not constant load of fourteen or fifteen tons. Captain Goodwyn, as previously stated, proves the iron he employs by a strain of ten tons, and never intentionally subjects it in the structures in which it is used to a greater strain than nine tons.

22nd. The conviction that on the point adverted to Captain Goodwyn is right in adopting the general practice of the profession in place of the particular practice of Mr. Dredge, appeared to us to render indispensable such an examination of Mr. Dredge's mode of fabrication as would best enable us to ascertain whether or not there was any peculiarity in it, warranting such a deviation from established practice; and having partly done so without finding any sufficient grounds for considering such an innovation *advisable*, we have now to observe that we have not arrived at this conclusion without advertence to the possibility of there being involved in his plan (as in the "spiders web" occasionally used for its illustration), *a consistent sort of weakness*—not easily reconcileable with such greater strength (therefore weights of material) as more experienced Engineers consider indispensable. Well assured that the insertion of a rope, or even of a "packthread," in the web of a spider, would prove destructive to some of the finer meshes, or parts of the fabric, and possibly lead to its total disruption,—it may, in like manner, be conceived that in one of Mr. Dredge's bridges a similar result might be produced by an increase of strength, not duly distributed, and which could only be duly distributed after a thorough knowledge had been obtained *of all the principles of construction involved.*

23rd. Noting that the eminent mathematician who attempted to investigate the principles of Mr. Dredge's mode of bridge construction appears only *partially* to have succeeded, inasmuch as he arrived at two rules,—one of which makes the tension on the oblique drop-rods uniformly increase towards the centre of the span, while[8] the other makes it regularly diminish as the centre is approached,—and, moreover, observing that Mr. Turnbull's theoretical

[7] This appears to be the case from the Specification of the Lever Bridge given in Mr. Turnbull's Memoir, and the section of iron said to be employed in its chains.

[8] See pages 38 to 40 of Turnbull's Memoir, in which the formulæ show the diminution of tension *from centre to pier*, and p. 55, where the result of the expression A C = A B cosec. A C B shows the tension to *increase from pier to centre!*

investigation of the mode of construction contains a qualification to the effect that "The foregoing" (*a tablet of terms* intended to show the law that regulates the strains) "may be considered as a *mathematical* ILLUSTRATION of the principle upon which the tapering of the chain depends; but the subject is still involved in difficulty as regards the distribution of the forces, and the position of the oblique suspending rods; for here there is no CONDITIONAL equation to direct us, *and on this account the successful application of the principle to practice must in a great measure depend on the sagacity and skill of the Engineer*[9] *by whom the fabric is raised*,"—there assuredly is too much reason to apprehend that the principles of fabrication involved have not yet been so developed as to afford the means of satisfactorily predicating what would be the result of great practical variations of detail.

24th. Mr. Dredge was of opinion that the quantity of material employed in the "Ballee Khâl Bridge" was "*greater than was indispensably requisite*:" Captain Goodwyn, fully convinced of the soundness of the general principle of construction, and that the accidental disruption of the structure was in nowise attributable to the principle, now proposes materially increasing the section of iron, or strength principally in the longitudinal side roadway beams. We have already expressed our conviction that such an alteration would be advisable; but being unprepared to demonstrate that the adoption of this suggestion would not render it advisable to give a proportionally increased section to the central, and still weakest, parts of the main suspending chains, it is only because Captain Goodwyn (who has bestowed so much time and attention on this particular description of bridge) does not see occasion for such an additional augmentation of strength, that we have abstained from recommending it.

25th. Excellent as the principle in question may be, we cannot but regret that the profound science which has been applied to its investigation has led to such an indefinite conclusion, as that its successful reduction to practice "must in a great measure depend on the sagacity and skill of the Engineer by whom the fabric is raised;" nor can we overlook the fact, that, notwithstanding this complimentary allusion to the practical instinct of the profession, the Civil Engineers of Europe have shown a marked disinclination to having any concern with its mathematical merits.

[9] See page 35 of the work published by Mr. Turnbull on Mr. Dredge's bridge.

26th. The unquestionable fact, that, apart from SOME THEORY, the approximate strengths of the component parts of a Dredge's bridge would be *totally indeterminate*, *necessarily* leads to the consideration of the manner in which its principles have been illustrated; and as Mr. Turnbull's investigation of the questions involved is considered the best, it becomes worthy of particular regard, that it commences with requesting the reader to "conceive" the half of one of the longitudinal roadway beams of a Dredge's bridge "to be *a heavy*[10] *and perfectly inflexible* bar (or '*lever*') *of uniform figure and density in all its parts*;" and although, for argument's sake, the party so appealed to need have no hesitation in making the admission required,—and, in consequence, will find no reason for resisting the conclusions to which it mathematically leads,—he still may reserve to himself the right of recurring to the starting-point, or to the degree of resemblance that in reality exists between the half bridge of a Dredge's beam and such a lever; and having, by reference to plans, and to the actual detail of such a structure, satisfied himself that the assumption is in a great degree imaginary, inasmuch as the half beam in question (formed of a series of iron bars joined by coupling links) is far more like the main suspending chain placed above it, than the inflexible lever alluded to, he necessarily feels disappointed that the demonstration has not been based on the actual *conditions of the case*, rather than on a *similarity* assumed in the first instance, and in the end found wanting. So dealt with, he becomes disinclined to admit that a demonstration based on *an illustrative assumption* is any demonstration at all; nor, fully acknowledging the merit of the reasoning as regards the lever, can he help mentally denying its applicability to the "Dredge's" half bridge *roadway chain, misnamed a beam*.

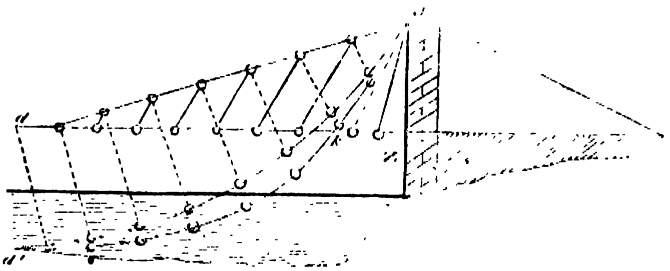
The lever, or beam, or half chain adverted to, is in reality any thing but inflexible; and bearing, at the best, more resemblance to a "*fishing-rod*" than to a *crow-bar*, it would assuredly have been satisfactory to have seen a *demonstration* (or even an *illustration*) of the points at issue, not totally excluding regard to its chain-like structure and modified elasticity.

27th The stress laid by the able investigator of the principles involved on the assimilation of the roadway beams to inflexible levers, serves, at least, to show that the conclusions at which we have arrived *in favour of trussing these beams in the strongest possible manner, would have the effect of making the theory,*

[10] See page 6.

assumed to be correct, *more completely apply to practice.* If, in fig. 12, *d Z*

Fig. 12.



were conceived to be an *inflexible* lever, all that the theory affirms might be true; but if, on the contrary, *d* Z were conceived to be (as it more nearly is) an *inflexible chain*, it is equally certain that, so far from being supported by the main suspending chain and oblique rods (*d f*), these would descend into some such form as represented by *f k d′*.

28th. On the subject of the extent to which *suspended iron chains* can be tapered with advantage, or in the manner that affords the greatest strength with the least material, Professor Moseley (in a letter written in reply to Mr. Dredge, and published in the 38th volume of the 'Mechanics' Magazine') makes the following observations to introduce a highly important practical conclusion: "I make no claim, you will perceive, to having first suggested or demonstrated the principle that the section of the chains should diminish from the points of suspension to the centre." To have done so, would "have shown great ignorance of the history of practical science. In the 'Philosophical Transactions' of 1826, this principle is fully stated and discussed by Mr. Davies Gilbert. A Table is even given by him to facilitate its application; and again by Mr. Hodgkinson, in a paper referred to in my preface, and published in 1831. Again I find it in the 'Analytical Statics' of the Rev. Dr. Whewell, published in 1833. It was from these writers, and not from Mr. Dredge's bridge, that I derived my knowledge of it, and I think it likely that it may be found recorded in theoretical works of yet earlier date. *I do indeed claim* (although I have nowhere in my work specifically stated that claim) *to have been the first to develope completely, that law of the variation of the section of the chains and of their curvature, which is consistent with the greatest economy of the material of the structure under its ordinary form.* Whilst preceding writers have either modified the conditions of the question, or, deterred by its analytical difficulties, have not

proceeded beyond that point at which it may be solved by approximation, my inquiries have been pushed on to the determination of formulæ expressing (in comparatively simple terms) the equation to the curve, and the section of the chains. WHEN APPLIED TO SUCH CASES AS OCCUR MOST COMMONLY IN PRACTICE, THE LATTER FORMULA SHOWS THE VARIATION OF THE SECTION NOT TO BE RAPID OR CONSIDERABLE."[11]

29th. The decision thus arrived at happily admits of practical illustration in a way that leaves no doubt of its general accuracy: supposing a bar or rod of iron of an inch square section and 100 feet long, suspending vertically by one of its ends the upper foot of its length, near the point of support, would obviously have the total weight of the entire rod to bear; while the lower part of its length, say one foot from the lower end, would only have the weight of one foot of its length to support, or so situated, the section of iron at the upper end of the rod would (from the weight of the rod itself) have 100 times the load to sustain that would be borne by the section of the lower foot of its length; and as an inch square bar of iron weighs nearly 3·31 lbs., this would nearly represent the strain at the lower end, while (3·31 × 100 =) 331 lbs. would be the total load or strain on the square inch at the upper end. To determine the sections or tapering that ought to be given to such a rod, say at 99 points of its length, so that each section might by the weight of the portion of rod remaining below it be uniformly loaded, would assuredly involve laborious calculation; but as in practice a suspended iron rod is never employed to bear merely *its own weight*, the solution of the problem is of little importance, save as a step towards the determination of the *far more common*, but much more complicated, question of *the degree of tapering* that can be given to a rod—suppose still 100 feet long, and one square inch in section—employed to sustain (say) a load of 9 *tons* or *of* 20,160 lbs. Now noting that the total weight of iron in such a rod would only be 331 lbs., it will be seen that this weight is so insignificant,

[11] In reply to this letter, Mr. Dredge states, (vol. xxxviii. p. 51 of 'Mechanics' Magazine,') "that *the section of iron in the chains of the foot bridge*" erected by him "in the Regent's Park ("and which has a span of 150 feet") "*is at the points of suspension* 8·904 *inches*, and at the centre ·742 inches, exhibiting a difference of 8·162 inches;" further, that according to Davies Gilbert's Table "the chains *at the centre* must have been 8·60 inches, or only ·304 inches less than at the points of suspension;" but as a central section of ·742, or less than ¾ths of a square inch, could never *of itself* have supported *the structure*, it becomes evident that the strength of a bridge constructed on Dredge's plan in reality mainly depends on the section or strength given to the side longitudinal roadway beams.

compared with the additional load of 20,160 lbs., as practically to be hardly worthy of regard; and (doubtless influenced by this consideration) it appears that in the construction of the new "Hungerford bridge," Mr. Brunel (who certainly knows much of what has been written, and all that has been successfully reduced to practice on the subject) has only deemed it necessary to increase *near the piers* the section of the main suspending chains, formed throughout the rest of their "length of 10 and 11 links alternately, to 11 and 12 links;" and this he has done *avowedly* "*as a provision of strength to meet the increased strain which takes place near the piers.*" Each of these links, it may be noted, is 24 feet in length, 7 inches broad, and 1 inch thick; and as the section of iron in these chains at the centre of the central span is stated to be "296 square inches," while the section at the piers is 312 square inches, it may not unfairly be inferred that he considered the difference, 16 square inches, an ample provision for the strain incident to the weight of the material used in the chains of the central span, viz., 352 tons; and this while they were employed in supporting an additional load in the drop-rods and central span roadway of 220 tons. It may moreover be concluded, that having in view the discussions which had taken place on the extent to which the *tapering principle* could be carried, he did not consider it expedient to apply *it* (*with vertical drop-rods*), *excepting in the comparatively small degree now brought to notice.*

30th. In the bridge alluded to, the roadway, which is only intended *for foot passengers*, has a breadth of 14 feet; its total length is 1352½ feet, and with a central span of 676½ feet (exceeding that of the Menai bridge by 110 feet), it has a *central rise of* 4 *feet*, *which* (where the main chains are nearly of uniform strength, and where in consequence they give ample support to the crown of the arch formed by the *roadway*) is an arrangement materially contributing to *its* strength and stability. Taking 17½ tons "as the impairing weight" of a square inch of iron which will only break under a load of 27 or 29 tons, the 296 square inches of iron in the weakest or central part of the main suspending chains of the bridge "would actually bear (296 × 17½ tons) = 5180 tons; while (296 × 5 tons =) 1480 *tons*, IS THE GREATEST LOAD THAT CAN BE BROUGHT UPON IT *by a crowd* standing close together, and which will weigh 100 lbs. per square foot." Thus loaded, it is stated that the entire weight borne by each of the two piers raised in the river would be about 1000 tons; and it hence appears, that apart from the weight of *this crowd*, the total weight of the main chains, drop-rods, and roadway, is 1155 tons, which,

as the roadway is 1352½ feet, makes the suspended weight, PER RUNNING FOOT, 17 cwt. 0 qrs. 9 lbs.

31st. With reference to bridges constructed on Sir S. Brown's principle, Drewry, (a well-known writer on the subject of suspension bridges,)[12] states, "the differences of tension at the different points on the length of the chains, are, in fact, so trifling that it is not worth while attempting to save weight and metal by nicety of proportion in a bridge of moderate dimensions;" and having given a Table extracted from THOSE COMPUTED BY DAVIES GILBERT (V.P.R.S.), for facilitating calculations respecting such bridges, he observes, that "the differences at any usual deflections are not such as to allow *any great saving of materials:* taking, for instance (with reference to the Table he quotes), the Menai Bridge to have a deflection of 1 in 15·1, and the whole weight of the suspended part, with its fair load, to be 1000 tons, then the tension at the *middle* would be 1878 tons, and at the extremities 1943 tons. The chains of the Menai Bridge contain 260 square inches of iron; if, therefore, they were proportioned throughout to their tension, they should contain at the middle $\frac{260 \times 1878}{1943}$ or only about 251 square inches, instead of 260 *square inches*—difference, 9 *square inches.*" Hence he proceeds to show the "weight of iron *saved* in a bridge which weighs 643¾ tons, without any load, would only be 3¾ *tons.* In the bridge proposed by Brunel, at Clifton,[13] it is stated that it was intended to give the chains near *the points of suspension* 496 square inches of sectional area, and from thence to diminish their sections towards the middle, where they would have contained 458 square inches; also that thus formed the *weight saved* would have been about 20 *tons*, which might have been usefully disposed of in other parts."

32nd. Having regard to the fact that in Dredge's bridges the difficulty of stiffening, or of trussing, the side *roadway* beams, and the roadway generally, increases in a ratio much greater than that indicated by *the direct* increase of span, we are inclined to believe, that for bridges *of very considerable span it would not at present be advisable to give a less total weight of material than that pointed out as requisite by the very careful experiments made by Sir Samuel Brown, Telford, Rhodes, Brunel, Palmer, Barlow, Rennie, Tredgold, &c.; but that* with a view to enabling this weight of material to be disposed of in the strongest possible manner, it would be highly advantageous to have a set of experiments instituted, calculated fairly to test, merely as regards con-

[12] See pages 166 and 167.

[13] Of 700 feet span.

struction, the merits of the various plans actually reduced to practice;[14] and, amongst the last of them, the modes of formation adopted by Mr. Curtis, by Mr. Motley, and by Mr. Dredge.

33rd. The plans of Mr. Curtis and of Mr. Motley have *here* been adverted to, because *both* (like Mr. Dredge's) in a great measure depend for stability on the strength given to the roadway, and because they both involve the use of main chains *directly descending* from the piers,—a mode of construction likewise (in the vicinity of the abutments) adopted by Mr. Dredge.

Both the plans referred to, as well as Mr. Dredge's, are represented to be free from vibration, and to be as strong as they can be made by the quantity of material employed.

34th. The experiments alluded to would be most valuable if carried on (as were Telford's and Rhodes's and Palmer's) both *on model and full-sized scales;* that is, on spans of 31½ feet, of 100 feet, of 140 feet, and *of* 900 *feet measurement, light material, such as iron wire, or small iron rods, being alike used for all the varieties of spans.*

To the results of such experiments *duly extended*, (on principles, that *if time had permitted*, would have been attempted to have been detailed,) mathematical reasonings might be applied with advantage, because with comparative certainty. Useful, invaluable as models are, for rendering a particular mode of construction intelligible, all practical Engineers, as also all mathematicians who are practically as well as theoretically acquainted with mechanics, know that *mere models* often lead to the most fallacious conclusions; and this from its being generally assumed (often without a shadow of satisfactory proof) that the dimensions of particular parts of the fabric only require to be increased in direct proportion to one of their linear dimensions, as for instance, in the case of bridges, directly in proportion to the spans; whereas extended or *full-scaled* experiments may be found to prove that the dimensions of some of the parts ought to be increased in some higher power than either the squares or cubes of the spans. On what principle it is that Mr. Dredge only allows the small increase of section he does to the side roadway beams of bridges of 400 and of 900 feet span,[15] compared with those he gives to others of 100

[14] Now carrying on in Calcutta.

[15] It appears that for a span of 100 feet, Mr. Dredge makes the section of the outside roadway longitudinal beams 5 inches × ½ inch, while the section of the corresponding beams for a span of 400 feet is but 6 × ¾ inches.

and 150 feet span, we have been unable to discover; and in consequence (and in the absence of full-scaled experiments) we cannot but conclude that Captain Goodwyn takes the wiser and safer course in giving the corresponding parts of the large-spanned bridges which he has planned much GREATER STRENGTH OR SECTIONAL AREA THAN MR. DREDGE CONSIDERS REQUISITE.

35th. In treating of the subject of "holdfasts" for the roadway longitudinal beams, Mr. Dredge justly *indicates* that provision should be made for the variations of their length incident to changes of temperature,—and noting that by experiments quoted by Telford, the expansion of a bar of iron of 50 feet long, under a change of temperature of 60° of the thermometer, is but $\frac{1}{8}$th of an inch,—and, consequently, that the total expansion of a bar of iron 250 feet long, or of the length of the roadway beams of the Ballee Khâl Bridge, would, under the greatest known local vibration of temperature, viz., 30 degrees, be but ($\frac{1}{8}$th × 5 =) $\frac{5}{8}$ths *of an inch*, one-half of which, or $\frac{5}{16}$ths of an inch, would take place at each end of the length,—it is certain that by many well known contrivances this trifling elongation or contraction of the roadway beams might be allowed for, without interfering with the principle of giving such ample and entire support to their ends as would be given by the "holdfasts" proposed to be employed by Captain Goodwyn. Resting, for instance, the ends of the beams on a *slightly elastic* substance introduced at the extreme ends of the cast iron boxes holding the beams in their places, would produce the desired effect; or this object might (partly as in the gridiron pendulum) be accomplished by making the expansion or contraction of one of the roadway beams counteract that of the other.

Employing back chains to these "holdfast boxes," we agree with Mr. Dredge (and ultimately with Captain Goodwyn) in regarding as unnecessary.

36th. Great *additional strength and power to resist tension* might be given to the *roadway by dowelling the longitudinal roadway planking laterally* together, or (supposing the thickness of the planks 3 inches) *by running at intervals of 4 or 5 feet apart, light iron rods transversely through the centre of the planking, or across the entire breadth of the roadway.*

Much additional strength might also be given to the roadway by partly fastening down the planking (bound together as above proposed) to the upper flanges of the transverse **T** iron roadway beams by BOLTS and SCREW NUTS, in place of *by "staples" or by tapering pointed spikes*, which, although clenched above at the *fine ends*, are liable to being straightened and drawn

out of the planking when any unusually heavy strain is brought on the bridge.

Drawing the heads or screwed nuts of bolts through 3-inch planks would (comparatively) be impossible.

37th. Had the roadway of the Ballee Khâl Bridge been formed as here proposed and described, the strength of its transverse sectional area of timber, UPWARDS OF 600 SQUARE INCHES, would have come *fully in aid* of the sectional strength of the side roadway iron beams, viz., 8½ SQUARE INCHES; and under such circumstances the fracture of these iron beams, or, at all events, the total disruption of the structure, could not have occurred.

38th. All the transverse T iron roadway beams, in place of every third one, ought to be so fastened to the side roadway beams as to keep these beams from bending outwards as well as inwards; and so fastened, each of them would partly have the effect of keeping the side roadway beams straight, *if they were so* (as they ought to be made if accidentally curved) before they were raised into their places.

39th. The complete adjustment of the lengths of the oblique drop-rods, and of all the parts of the bridge, ought to be accurately effected before the *roadway planking is laid*, and, in consequence, before any load, either irregularly or uniformly distributed, can be brought on the roadway platform, by broken stone, brick, &c., used in the formation of the road.

40th. Totally avoiding cast iron boxes, as the means of connecting the oblique drop-rods with the roadway beams, would be highly advisable; inasmuch as the bolts used for securing these boxes to the BEAMS have the effect of materially diminishing their sectional strength.

41st. Forming the side roadway beams in a manner that would render it possible to dispense with the coupling links, and with the numerous bolts joining the links and BEAMS together (greatly to the detriment of the strength of the LATTER), would also be an improvement.

42nd. Avoiding the use of cast iron, to the utmost possible extent, would, on various grounds, be advisable. In small castings, such as are employed for the ends of the transverse roadway beams (and which are formed according to patterns used by Mr. Dredge), no degree of care will, in all cases, insure the absence of flaws, or of brittleness.

43rd. It appears that the *weight* of a bridge, on the "*old principle,*" *would be* "*sixty-five tons;*" and in a note received from Captain Goodwyn, of date the

17th of August, it is stated that SIXTY-THREE TONS will be the total weight of iron in the (new) Ballee Khâl Bridge.[16]

44th. There were in each of the two "central links" of the Ballee Khâl Bridge 3 square inches of section, or jointly, 6 square inches; and in the two side longitudinal roadway iron beams, there were jointly $8\frac{1}{2}$ square inches; and, adding these sectional areas together, (viz., 6 square inches + $8\frac{1}{2}$ square inches,) it appears that (including the section of the outside roadway beams) the total section of iron at the centre of the span (not deducting the section of the bolt-holes cut in the side roadway beams) was $14\frac{1}{2}$ square inches. In the new bridge, Captain Goodwyn proposes making the joint section of the side roadway beams 13·75 square inches ($=2 \times 5\frac{1}{2}$ inches $\times 1\frac{1}{4}$ inch); and if to this sectional area be added that of two extra side plates, extending 21 feet on each side of the centre of the span, viz., 16·5 square inches ($=5\frac{1}{2}$ inches $\times \frac{3}{4}$ inch $\times 2$), and the section of four centre links, *proposed by his note of the 17th of August to be increased to $1\frac{5}{8}$ inch in diameter, or jointly to 8·28 square inches*, THE TOTAL CENTRAL SECTION *of the new* CHAINS and roadway beams WILL BE, FOR 42 FEET AT THE MIDDLE OF THE SPAN ($13·75 + 8·28 + 16·5 =$) 38·53 square inches, or 24·03 square inches in EXCESS of the *former sectional area.*

In a bridge on the old plan of 250 feet span, with $\frac{1}{10}$th deflection, the safe section of iron in the chains, with a load of 120lbs. on the square foot of roadway, would be 48 square inches; and it hence will be seen that the strength represented by the total differences of section (48 square inches — 38·53 square inches), equal (nearly) 10 square inches, approximately represents the strength remaining to be supplied by the *roadway platform;* acting, as it *is intended to do,* (and as, if formed as above proposed, it would do,) by compression, in opposition to tension, from the centre of the span.

[16] Respecting this approximate equality of weights of bridges formed on *the old* and *Dredge's* plan, Captain Goodwyn, in the note alluded to, represents that in the "New Ballee Khâl Bridge 20 tons will be the actual weight of longitudinal and transverse beams of the roadway. So that the difference between a bridge of 250 feet on *old* and *new* principles (estimating the same items in both, only chain drop-rods and railing) is as follows:

Old principle = 65 tons,
New ,, = 43 tons,

where timber forms the roadway of the former, and 20 tons of iron the latter."

The total weight of these new beams will, he states, be "but two tons in excess of that of the old beams," and that, proposing to employ eleven tons of iron plates, spiked transversely to the planks, all along the bridge, at four inches apart, there will be totally a less weight on the roadway of seventy tons, than while, as at first, it was loaded with ninety tons of "*Koah*," or roadway material.

45th. In addition to the alterations now described, straightening or renewing all the iron works bent or twisted, and replacing by *new castings* such of *these last* as were found broken, will be observed to be the principal measures proposed by Captain Goodwyn for adoption in the re-erection of the bridge; and with the whole of the iron-work "*re-tested*," as proposed, *and in conjunction with such methods of trussing and relaying the roadway platform as have above been adverted to*, we are of opinion that it would be advisable to employ the materials of the former bridge in the manner he has recommended, *or here indicated;* and further, that with the improvements he has suggested, and the adoption of such alterations of detail as have now been brought to notice CAREFULLY EXECUTED, the new structure would be proportionally stronger than any one previously constructed on the same principle, all of which, erected in Europe on Mr. Dredge's plan, have answered the purposes for which they were intended, and "are now in good order."

46th. By the reconstruction of the bridge under the immediate *superintendence of Captain Goodwyn, as with reference to many considerations would be requisite*, the fairest possible trial would be given to the principle involved; and in the course of locally directing the operations relating to its replacement, he would have an opportunity of experimentally ascertaining the best means of obviating the difficulties (apparently of no formidable nature) stated to have been encountered in the putting up of smaller bridges formed on the same plan, at stations comparatively distant from *Calcutta, and therefore less in the way of easily obtaining well-qualified workmen.*

47th. Based on the information thus acquired, Captain Goodwyn will be able to furnish the local executive officers with *supplemental instructions* for the erection of this particular description of bridge, so minutely detailed as to leave little room for the exercise of the professional ingenuity they are known to possess,—this under the assumption of the conclusions derivable from the reconstruction of the Ballee Khâl Bridge, and from the "*full-scaled experiments*" *alluded to*, being of a nature to warrant the more general introduction

of Dredge's "*Taper Bridges*," strengthened and improved as proposed by Captain Goodwyn.

E. GARSTIN, Lieut.-Colonel, President.
W. N. FORBES, Lieut.-Colonel, Engineers.
A. IRVINE, Lieut.-Colonel, Engineers.

Calcutta, September the 6th, 1845.

Appendix to the Committee Report on the Failure of the Ballee Khâl Bridge as originally constructed in close Adherence to Mr. Dredge's Principles.

Principle of construction.

The principle on which the bridge was constructed is that of tension in the suspending line, or line of the chains and auxiliaries, and compression or rigidity in the horizontal, or line of the platform; these joint powers acting in the support of the fabric and traffic.

Test of strength of various parts

It is my duty to furnish the Committee with proofs of the efficiency of the bridge in all its parts, as constructed, because the result justifies the assertion, that the failure is *solely* attributable to a *deviation* from the principle during the progress of setting up,—an error caused by anxiety to remedy an accident, and *not* from any fault in the principle or want of strength in the combination of the parts. The tension on the upper link of the chains may be computed by half the weight × by the cosecant of the angle of suspension: this being a well-admitted fact, needs no further proof. The area of the platform supported by the chains (exclusive of that upheld by the rods direct from standard) was $192 \times 18 = 3456$, which, at 150lbs. per square foot, for weight of bridge and traffic (an extreme assumption), gives 518,400lbs., or 232 tons and $\frac{232}{4} \times 2{\cdot}95$ (cosecant $19^{\circ}\ 51'$) $= 342$ tons total tension on each end, or 171 tons on each chain.

Chains

Now the upper link consisted of 15 rods of $1\frac{3}{8}''$ diameter $= 22\frac{1}{2}$ square inches, which, at 10 tons per square inch, gives a power of 225 tons, or 54 tons in excess of that required. Supposing each set of oblique rods to deduct an amount of tension from the links to which they are attached, equal to the force exerted on them respectively, there will remain a tension on the centre link in an extreme case of 36 tons (306 tons being the sum of the extreme tensions of the auxiliaries), or 18 tons in the centre of *each chain.* The section of *each* centre link is 3 square inches, or equal to 30 tons, one rod only being dropped from each link in succession.

Oblique auxiliaries.

A space upheld by four oblique auxiliaries is 8×16, or a weight of 9 tons: now, with reference to the angles at which the auxiliaries are set, those from the upper link will have an extreme tension of 15 tons, and those next to the centre of 37: the centre rods, being eight close together, and only having a space of half the above to uphold, cannot

bear reference here. The sectional area of four oblique rods is 4 inches=40 tons; so that those nearest the centre were strong enough.

The platform was composed of two external longitudinal beams, $5\frac{1}{2}'' \times \frac{3}{4}''$, two internal ditto, $4'' \times \frac{1}{2}''$, crossed by **T** iron transverse beams of 4-inch web, and 3-inch table, $\frac{1}{2}$-inch thick, at intervals of 2′ 7″—every third of which was trussed with five truss-rods securely fastened to castings on the external longitudinal beam. The two internal longitudinal beams divided the bearings of the transverse ones into spaces of 6 feet each. Thus trussed and framed, with $3\frac{1}{2}$-inch planks spiked to it, the ends of the platform abutted firmly in the piers, the longitudinal beams being doubly bolted into large cast boxes, which were set into stone blocks set firm in the masonry, with the weight of the standards on them. Platform.

Thus the principle was adhered to, the bridge having been erected with the chains acting by tension against the firmly abutting horizontal line of the platform. Principle adhered to in first instance.

Just before the last planks were laid down in the centre of the bridge, the overseer in charge had, during my absence, in innocent ignorance of the mischief he was doing, loaded the north end of the platform with 40 tons of metal, leaving the other end comparatively light. A storm at that critical period aided in compressing the loaded end of the platform violently against the pier, and (having no counteracting power on the opposite side) by this means the outer longitudinal beams were bent outwards between the third and fourth socket, or about 30 feet from the pier: the final adjustment had not yet been made. Cause of accident previous to disruption.

To effect the repairs to these portions of the beams it was necessary to remove them; to effect which, under the violent effect of the tension then existing, was a matter of extreme danger and difficulty. Temporary release from the effect of the power seemed the only plan; but I first loaded the opposite end of the bridge, to reduce the compressive force at the north end. I then, in an unguarded moment, not allowing time for calculation of the probable effect of what I was about to do, released the ends of the platform from all connection with the piers, and thereby for the time subverting the principle of construction; for the platform being free to move horizontally either way, became subjected to the whole tensile force of the oblique auxiliaries, the sum of one-half of which at the centre, with the load then on the bridge, was 190 tons at least, or 60 tons above what the power of the longitudinal beams and centre links were equal to; and the natural consequence was, disruption at that point; and the fact is proved from the fractured parts. The eastern longitudinal beam at the centre appears first to have been torn asunder, followed by the centre link of that side, which is fractured at its junction with the next link: nearly the same effect occurred on the west side in the centre, with this difference in the result, that the lower eyes of the link next the centre have given instead of the centre link itself, whilst the longitudinal beam was not fractured in the centre, but drawn out of the coupling plates at the joint nearest the centre. I trust the Committee will thus clearly see that the sole cause of the misfortune was owing to the Error committed in attempt to repair the accident. Position of rupture. Not owing to defect in principle or strength of material.

release of the ends of the platform from the piers, thus causing the immense tension on the platform which by the principle of its construction it was never intended to bear, and that the principles themselves are in no way affected or weakened by the result; for had the ends been retained in the masonry as they were originally put up, the bridge would now have been standing and perfect.

Extent of damage

The effect of the disruption has been to twist and distort the longitudinal and transverse beams, and many of the oblique rods, a few of which only are broken, evidently by torsion from confinement in the castings at the time of the fall, many being bent at a right angle. The railing has received but little injury; the chains are entire with exception of the links above referred to, and the planking has all been recovered undamaged.

The upper portions of the standards, about 5 feet in height, appear to have been shaken, and a stone supporting the cast iron saddle on one of the standards of the side which first gave way, cracked; the saddle, however, being dovetailed into it, has preserved it entire, and a cramp or two is all that is required. I deemed it necessary to take down the portion of the standards above alluded to, with the connecting arch to the spring: this I trust the Committee will approve of. I am endeavouring to extricate the stones and boxes in which were fixed the ends of the longitudinal beams: these are three feet under the base of the standards, and must be taken out to be replaced by new boxes and fastenings for the renewed platform. It is my wish and endeavour to get them out without further dismantling the masonry; but I will leave it for the Committee to decide on the expediency or otherwise of the measure.

My intentions for the renewal of the bridge are as follows:

Intentions regarding renewal

To replace the outer longitudinal beams by new ones of larger section, to allow for any deficiency of strength caused by bolt-holes, and to form the centre connection by wrought iron plates, $5\frac{1}{2}'' \times \frac{3}{4}''$, in lieu of the cast plates formerly used. The section of the outer longitudinal beam to be either $5\frac{1}{2}'' \times 1\frac{1}{4}''$, or $6'' \times 1''$, according to the iron procurable: the first I am sure of obtaining, the latter I am not yet.

The inner longitudinal beams, $4'' \times \frac{1}{2}''$, carrying the untrussed transverse ones, are, I think, sufficient for their work, but shall be strengthened if deemed advisable by the Committee.

The transverse **T** beams can be straightened and refitted.

The oblique rods can be straightened, and those broken easily re-welded; but little is required to the railing, save the straightening of a few braces, the renewal of the stays, and a portion of the hand-rail.

The small castings, boxes, and sockets, must be renewed to fit the increased dimensions of the longitudinal beam, and to replace the broken ones.

The whole of the iron-work to be proved again before re-setting.

No means of proving iron of large scantling.

I beg to bring to the notice of the Committee, that (though not that I am aware of in this instance) there may be a flaw in the longitudinal beams of bridges wherein a large section of iron is used, which I have no very correct means of testing: the power of

the proving-machine in the iron yard is scarcely equal to a proof of more than 36 tons effectually; and though the portions of the platform are each separately subjected by vertical loads to much more than the actual weight they will have to carry, yet that is not the test necessary to discover a flaw in a particular piece of iron.

Annexed is a plan and section of one pier of the bridge, showing the mode of connection of the platform as orginally constructed, and explaining the mode in which I detached the parts from the firm hold they had, in order to effect the repairs to the injured beams.

A A A A are four bolts, and B B a transverse 2-inch bar, connecting the four longitudinal beams to their cast iron boxes. These boxes are let into the heavy stones with lead, and the stones themselves set firm in the masonry. Thus all was secure, as the standards were built over the two outer boxes.

The same letters refer to both plan and section.

To effect the release of the outer longitudinal beams from the effect of the compression, which prevented their removal, I cut out the four bolts A A on the north side, and cut also through the 2-inch bar, first at B B, and afterwards at C C, by which means it was drawn out, and I opened out recesses (marked D D D D) 6 inches in rear of the stones, at the same time setting free the ends of the planks. The whole of the north end was thus entirely relieved from compression and disconnected from the pier. On the south side I had removed the bolts A A A A, and cut through the bar at B B, knocking out the screwed ends from the boxes. The parts at C C, on the south side, had not been cut; but on the fall of the bridge the two central stones and boxes were drawn out from the platform, the weight of the piers not being on them. It will thus be seen, that when the external longitudinals on both sides were set free, how completely the compressive force was annihilated, and what an amount of tension was thereby transferred to the centre of the platform, which caused the disruption, and that alone.

As further conclusive of the efficiency of the chains and oblique rods, I submit to the Committee an elevation of the half curve of the bridge on a large scale, on which the several angles are correctly laid off, the tension on each set of oblique rods correctly calculated and laid down, and the tension on each link deduced as a resultant from the other two forces acting at the same point—namely, the link immediately below and the oblique rod. A triangle of the three forces is constructed for each separate link, from which it is shown that the tension on the link next the centre (in an extreme case assuming 125 lbs. per square foot as weight of bridge and contingent load) could only be 38½ tons, and that on the upper link 126 tons. This agrees with all the other calculations originally made to prove the tensions on the different parts. Now to meet the 38½ tons extreme tension, the lower link had 4½ square inches of iron = 45 tons permanently, and the upper link had 21 square inches = 210 tons, to meet a tension of 126. The tension on the centre link has been before stated, and could not be exposed to more than 20 tons on each side, for which it had a section of three square inches = 30 tons.

Further proof of the efficiency of the construction.

Strains on chain.

Strains on auxiliaries.

The greatest strain is shown to be on the central auxiliaries, and is on the plan stated to be 20·12 tons; but that is on the assumption that these rods uphold an equal portion of platform with all the rest, which is not the case, as will be visible from their position; the strain on them would, therefore, not be more than 16 tons: they have two square inches = 20 tons permanent on a breaking strain of 54 tons.

H. Goodwyn, Captain,
Civil Architect.

Copy of a Letter from Captain H. Goodwyn *to Major* Greene, *Secretary to the Military Board.*

Iron Bridge Department, Fort William, 28th August, 1816.

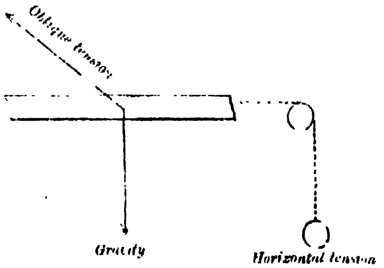
Sir,

I have the honour to forward the following Report on the result of a series of experiments, instituted by me, in communication with Colonel Forbes, for the purpose of testing a newly-suggested proposal for the construction of iron tension bridges, on a principle, the theoretical details of which were submitted with my No. 124, of 3rd November, 1815, in forwarding the Report connected with the proposed bridge at Agra.

2. The authority under which these experiments were undertaken was conveyed in the third paragraph of a letter, No. 1931, of 28th October last, from the Under Secretary to Government to your address, and annexed to your No. 5138, of 31st idem, to the address of the Superintending Engineer, South Eastern Provinces.

3. Fig. 1 (Plate XXIX.) is illustrative of the first experiment, which was intended to test the theory of a system based on the "resolution of forces," as set forth in the statement appended to my letter, above quoted, as explanatory of the proposed construction of the Agra Bridge.

4. The idea of compression in the horizontal line having, from actual proof, been deemed untenable in bridges of any ordinary span, the opposite power of tension has been admitted as the third in the series to produce an equilibrium jointly with those of gravity, and the tension in the oblique direction from chain to platform, thus:



The oblique and horizontal force in a series bearing theoretically a certain proportion to each other with reference to the obliquity of the former, the weights at each point being uniform, this experiment was instituted to prove practically how far that theory was correct.

5. It was also intended to illustrate practically the theory relative to the position and power of the chains, the links of which are calculated to be true resultants from the two forces immediately below them in the chain; viz., the link and oblique rod attached to the lower extremity of that resultant.

6. The centre link being horizontal, its magnitude, or power, is made any proportion (within perfectly safe limits) of the upper link, which denotes the full power of the structure; the central obliqae rod is placed at such an angle with the platform, that there shall be the least possible difference between it and the angle of the rod next the pier, and this is regulated so that the height of the point of suspension shall not be less than $\frac{1}{10}$th of the span; for it is evident that the less the oblique rod is inclined, the less is its magnitude, and the link from the centre will consequently have less rise, the greater tension coming on the horizontal centre link (*vide* annexed figures), where the strain on

Fig. 1.

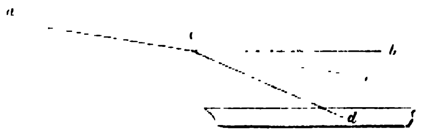
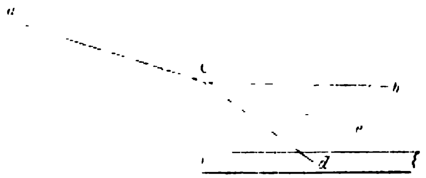


Fig. 2.



the centre link is increased, or diminished, as the line *a c e* approaches nearer to *c b*, or *c d*. The direction and magnitude, therefore, of the first starting link in the chain will be determined by those of the centre link and central oblique rod; and as the direction of all the other links is regulated by the first, it is necessary so to dispose the central oblique rod, that the total deflection be neither so great as to cause undue oscillation, nor so low as to cause undue tension, and consequently extra expense to meet it.

7. Fig. 1 (Plate XXIX.) shows the experiment which was to prove whether, individually or collectively, the several sets (three forces applied to any point to produce equilibrium) of forces which may be applied to any single rod, link, or the entire series of rods and links, will be proportionate to the different strains, which are those calculated as due to the parts of a bridge of 100 feet span, 16 feet wide, constructed on the above principle.

8. The experiment was on full scale as regards heights and distances, but formed of material $\frac{1}{20}$th of the strength of the real bridge, the uniform weights at the points of junction of the oblique rods with the platform being in the same proportion, allowing 120 lbs. per square foot.

The point of suspension is 2 feet from the centre of the standard, making the half span of the chain 48 feet.

9. The power of the centre link, by actual construction, was made equal to $\frac{1}{4}$th that of the upper link, or whole amount of tension which would be due to a uniform chain, and the $\angle$ of the central oblique rod determined to be 30°, the deflection being $\frac{1}{11}$th.

10. The chain was not at first attached, but the forces necessary to preserve equilibrium at the points of attachment of the oblique rods with the platform, first attended to, as follows, each of the portions of platform (c, c^1, c^2, &c.) being separate at first, and afterwards flexibly connected.

To the portion (c) with a weight (d) of 56 lbs. was attached a single rod (a) passing over a pulley at point of suspension; a weight (x), and part of weight (Y), passing over a pulley in the horizontal line, were added in such proportions till they produced an equilibrium, *i. e.* till the portion of platform (c) was made horizontal by the joint effects of the two weights x and Y.

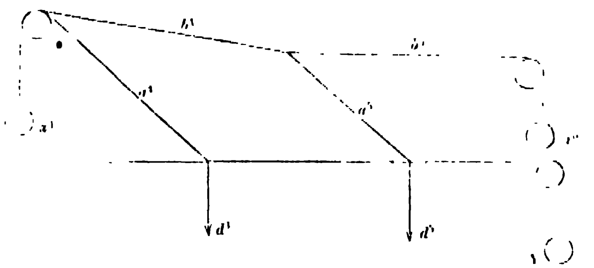
11. The subjoined Table shows in its several columns what the proportions of the weights (x, x^1, x^2, &c., and Y) should be, theoretically calculated, to produce equilibrium at the different points as the rods were successively attached; and it also shows what the actual weights were particularly applied in succession, as well as the collective results on the whole series, with the differences.

12. At the distance of 7 feet the oblique rod (a^1) was attached to a second piece of platform (c^1), with its weight of 56 lbs., which latter was also connected to the piece (c) flexibly; the weight (x^1) appended to the rod (a^1) and weight (Y), increased till the equilibrium was produced, or both pieces of platform (c, c^1) were in a horizontal line. In like manner were all the obliques (a^2, a^3, a^4, a^5) attached to the several portions (c^2, c^3, &c.) of platform, and the weights added and corrected: when the whole series was complete, the weight Y had attained its maximum. The Table will show the differences between the actual weights (Y, Z, x^1, x^2, &c.) and the numbers on the Plate, which are those mathematically calculated as due to the several rods and beam.

13. The result shows that the whole were increased slightly beyond the calculated amounts; but this may be attributed to the friction of the chains upholding the oblique rods, which passed over cast iron pulleys, 9″ diameter. It will be observed, however, that the increase was proportional: thus the original calculated weight (x^1) due to the oblique rod (a^1) was 74 lbs., but, to produce equilibrium, required to be increased to 95, and the calculated total amount of weight Y was 406 lbs., afterwards practically requiring 519; but the numbers 74 and 406, and relatively proportional, to 95 and 519.

14. To prove the proportions due to the chain links in connection with the rest of the

parts, the oblique rods were severally disengaged from the pulleys, and attached to the chain as follows. The rod (a^5) was first attached to the centre link (b^5), the outer end of which was fixed to a chain passing over a pulley, and to which was appended weight x^6. The lower end of the link (b^4) was likewise attached to the junction of the two rods, and its upper end to a chain passing over a pulley with weight x^4 appended, the intermediate pulley and weight x^5 being removed. In this position was remarked the amount of the weights required to produce equilibrium, and what proportion x^4, which denoted the tension on link b^4, bore to the numbers, mathematically calculated: the result of the whole is shown in the Table, and the annexed sketch, the position of the rods at this



period (b^4), being a true resultant of b^5 and a^5. Each other link (b^3, b^2, &c.) was then added in succession, the weights (x^4, x^5, &c.) being withdrawn in turn, and that attached to the link under investigation being increased as the experiment approached the upper link (b), when the weight Z denoted the total tension on the upper link.

15. Thus was shown the separate tension on the oblique rods, the horizontal tension on longitudinal beam, and the tension on each link of the chain: their results, as compared with theory, are noted in the Table, and are satisfactorily approximate to each other.

16. It was stated in the Report of the Committee on the Ballee Khâl Bridge, and referred to in the second paragraph of my statement on the resultant system, before alluded to, that the power of the longitudinal beam at the centre, added to the power of the centre link, should, together, be nearly equal to the power of the upper link, so that whatever power was taken from the chains in the centre, should be compensated for in the longitudinal beam. Now the result of the experiment entirely coincides with that opinion, and confirms the view taken of this part of the construction. The total corrected amount of weight Z was 1086 lbs., and the sum of weights x^6 and Y, or 572 + 519 = 1091 lbs.

17. Experiment the second, fig. 2, was proposed by Colonel Forbes, on Mr. Dredge's extreme oblique principle, with the sole exception that the central portion of the roadway beam formed the horizontal connection between the first slanting links on each side of the centre, thus: as in the fig. 2, as before, c, c^1, c^2, &c., denote the platform, b, b^1, b^2, the chain, the lower link of which is attached near the centre to the longitudinal beam at c^3. In this position only can Mr. Dredge's theory of a vanishing strain

existing in my centre link (N dotted line) be granted; but at the same time the roadway beam must be equal (nearly) to the full section of iron in the upper link, as the result proved. The weights Z and Y were alone necessary for this experiment, the weights d, d^1, d^2, d^3, being, as before, ½ cwt. each.

18. The span of this half curve was only 40 feet, yet it required 1242 lbs. at Y, and 1302 lbs. at Z, to produce equilibrium, being a greater weight than in the former experiment, in consequence of greater tension being called into action by the greater obliquity of the rods; and a proof that in Mr. Dredge's construction there is not iron enough in the centre of the longitudinal beam to resist the tension existing there. This experiment showed much more rigidity than the former one, being more powerfully acted on; but to have manufactured it sufficiently strong to resist the tension, would have entailed a heavier outlay than the former.

19. There is no doubt but that this construction of making the longitudinal beam act centrally as part of the chain would tend to stiffen the structure, and might simplify the details in small spans; but in large spans, where the centre link is of great substance, and with a double chain, practical difficulties occur which would render the centre link a necessarily distinct feature, and prevent its absorption into the roadway beam.

20. The reason why the chains are drawn tangent to the railing is to enable the railing to be placed centrally under the chains; for if the chains were tangent to the roadway, though there would be a decrease in the height of the standards, there would be a loss of 2 feet in width of platform; for with a wide chain dipping below the railing, the stanchions supporting it must be placed 1 foot on each side, within the central line of the chain, in order to avoid contact with it; and an extra 2 feet of platform is more expensive in its consequences on the amount of iron than an additional 4 feet of masonry on the standards.

21. Experiment 3rd, of which fig. 3 is illustrative, was a construction on the resultant principle, similar to Experiment 1, carried to a much larger extent. The fig. 3 shows only one half of it, as it was an entire curve of 490 feet between the points of suspension, the lengths of the rods and beam, heights and distances, being to a full scale, whilst the sectional area of the iron was $\frac{1}{100}$th part of reality. The sections of the whole of the parts are given (Plate XXIX.), and proof calculations that each was correctly proportional to the full sections of the actual bridge. The standards were formed of spars, firmly supported by struts in front,[1] and stayed back with ropes and chains, the latter having tackle on them to correct the perpendicularity of the masts, should they yield to the load.

The horizontal beam was upheld by forty-four rods from the chain and six direct from

[1] Left out in drawing, to prevent confusion.

each standard; the chain double, tapering in the centre to a power equal to $\frac{1}{5}$th the upper link.

The angle of the centre oblique rod 25°, and that of the one next the standard 38°; so that there was only a difference of 13° between the two extremes, divided amongst twenty-eight points, or a difference of tension between the extremes in the proportion of 2·63 to 1·62.

The deflection of the chain was equal to $\frac{1}{12}$th the span.

The section of the longitudinal beam at the centre, added to the section of the centre links, was equal to the sectional area of the upper links of the chain.

22. The whole of the experiment being, as before said, $\frac{1}{16}$th part of reality, is a model of the curve, which was designed for the Agra Bridge, the whole of the details of which were recorded in the Estimate and Report, submitted with my No. 124, of 3d November, 1845; and the result of this experiment will go far to prove the theory then advanced to be correct.

The calculations show the proportional load for the experiment to be 1352 lbs., at the rate of 120 lbs. per square foot of platform, to be uniformly distributed over 56 points. This was done by slinging a basket at each point, and gradually loading them up to the amount of 57 lbs. each.

23. When loaded with 24 lbs. in each basket, or 51 lbs. per square foot (exclusive of weight of experiment), the deflection in the centre, after the masts were made upright, was $1\frac{3}{4}''$ only in the centre.

When an extra load of 16 lbs. per basket, making in all 40 lbs., or $81\frac{1}{2}$ lbs. per square foot of platform, the deflection in the centre was $5\frac{1}{2}$ inches, and midway between the centre and standards, on one side $1\frac{1}{2}''$, and on the other $2\frac{1}{4}''$, on account of the greater flexibility of one mast than the other. When the full load of 57 lbs. each point, or 120 per square foot, was put on, the deflection was $13\frac{1}{4}$ inches in the centre. This load was allowed to remain on 3 days: it was subsequently unloaded and re-loaded several times with nearly the same results; and after the lapse of 17 days from the period of its first being loaded, when all the weight was taken out of the baskets except 24 lbs., which is proportional to the weight of the suspended platform of the real bridge without the traffic weight, the longitudinal beam sprang up to within $\frac{3}{8}$ths of an inch of the horizontal line in which it was first constructed.

24. Thus was this very extended curve, formed of such exceeding slender material, not any of which could be proved before it was put together, found equal proportionally to the greatest amount of the traffic load that could on any extraordinary occasion come on the bridge without derangement of any of its parts: the combination appeared as stiff under the load as could reasonably be expected with such slender wires, and fully bore out the results detailed in Experiment No. 1, and the mathematical demonstration of the powers of the bridge, as set forth in the Specification of the Agra Bridge.

25. Subsequent to the above detailed loading, I continued adding weight to the

baskets, and correcting the masts as well as the power of the tackle enabled me to do, till the weight in each basket amounted to 81 lbs., when the longitudinal beam was torn asunder at the distance of 25 feet from the centre, and the whole immediately buckled up. The breaking weight was therefore 174 lbs. per square foot of platform, or a tension of 15 tons per square inch of that slight material, the weldings of which were with difficulty made, and the strength of which there was no means of proving.

26. I cannot imagine any further proof to be necessary of the efficacy of such a system as has been proposed, manifestly having for its object the avoidance of the defects of both the uniform and extreme oblique systems, combining the strength and solidity of the former with the rigidity, economy, and more advantageously scientific construction of the latter.

27. In this construction, admitting the action of tension in every direction, and where the rods and bars are drawn in the direction of their length, the full amount of tension that can possibly affect every part of the structure can be accurately ascertained, and thus certain data are afforded from which to proportion the sectional areas of every part of the bridge.

I have the honour, &c.,

H. GOODWYN,

Captain, Engineers.

Scantlings of Rods of Experiment No. 3.

Each chain	Upper link	$\frac{15}{32}$	of one inch.
	2 ,,	$\frac{29}{64}$	
	3 ,,	$\frac{28}{64}$	
	4 ,,	$\frac{27}{64}$	
	5 ,,	$\frac{26}{64}$	
	6 ,,	$\frac{25}{64}$	
	7 ,,	$\frac{24}{64}$	
	8 ,,	$\frac{23}{64}$	
	9 ,,	$\frac{22}{64}$	
	10 ,,	$\frac{20}{64}$	
	11 ,,	$\frac{19}{64}$	
	12 or centre	$\frac{18}{64}$	

Oblique rod $\frac{1}{8}''$ diameter.

Longitudinal beam at centre $1 \times \frac{3}{16}$.

,, ,, 7th space from centre $1 \times \frac{9}{64}$.

Explanation of the relative Proportion between the Experiment and the real Bridge

Full section of two chains one side of the real Bridge.

Upper link, 17 bars $2 \times 1 = 34 \times 2 = 68$ square inches.

Diameter of experimental upper link, $\frac{15}{32}$ of one inch.

Area of which ·178 and $\cdot 178 \times 2$ ch. $= \cdot 346$ section of two chains:

$\cdot 346 \times 176 = 67 \cdot 8$, or section of real Bridge.

Area of Platform, real Bridge, $468 \times 11 = 5148$ square feet:

$5148 \times 120 = 617760$ lbs. on real Bridge.

$\frac{617760}{196} = 3152$ lbs. total load for Experiment.

$\frac{3152}{56} = 57$ lbs. on each point of Experiment.

Area of oblique rods of real Bridge 2·405 each.

Diameter of rods of Experiment $\frac{1}{8}''$ or sectional area ·012:

$\cdot 012 \times 196 = 2 \cdot 352$, or very nearly the section of real Bridge.

Sectional area of longitudinal beam of real Bridge at centre, 37 inches;

remainder 27 beyond the 7 lb. oblique rod.

Section of experimental beam at centre $1 \times \frac{3}{16} = \cdot 188$;

and $\cdot 188 \times 196 = 36 \cdot 848$, or nearly the section of real Bridge.

Remainder of section, $1 \times \frac{9}{64} = \cdot 141$ at the 7th rod:

$\cdot 141 \times 196 = 27 \cdot 636$, as nearly as possible the section of real Bridge.

Table explanatory of the previously calculated Theoretical Tensions, and subsequently practically proved Results, on an Experiment undertaken to test the Taper Chain Resultant System.

	Oblique Rod Forces.			Chain Link Forces.		Total Tension Horizontal Line.				Total Tension Upper Link.			
	Previously calculated.	Practical result.	Difference.		Practical result.		Previously calculated.	Practical result.	Difference.		Previously calculated.	Practical result.	Difference.
x or a	68			b	814								
x^1 „ a^1	74	95	21	b^1	750								
x^2 „ a^2	81	102	21	b^2	678								
x^3 „ a^3	92	107	25	b^3	596	Y	406	519	113	Z	814	1086	
x^4 „ a^4	104	132	28	b^4	500								
x^5 „ a^5	112	145	33	b^5	400								

EXTRACT FROM A LETTER FROM MAJOR GOODWYN.

"A bridge on Mr. Dredge's principle, which was put up a short time since across the Kubudduk River, near Jessore, has fallen.

"This bridge was of a central span of 175 feet, and two side openings of 43 feet, measured from centres of standards. Width of platform 10 feet; ordered, intended, and *guaranteed* by Mr. Dredge to stand any traffic, to bear the usual load of 75 lbs. per square foot of platform in excess of its own weight, and to be tested up to 10 tons per square inch of iron.

"The section of the chains at the upper link was 16·84 inches, formed of $\frac{7}{8}''$ rods, and tapering thence to a single rod in the centre or section of 1·208 inches in both chains.

"The oblique rods were in pairs, the section of each pair being ·884 inch or 1·768 inch on both sides, supporting a length of about $5\frac{1}{2}$ feet of platform, and forming angles with the platform varying from 59° to 10° at the centre.

"The longitudinal beams to which these rods were attached, were, on each side, $5'' \times \frac{3}{4}''$, or having a total section on both sides of 7·5 inches, or about 6 effective inches to resist tension, rejecting the area of the bolt-holes.

"Such are the sections of the parts subjected to tension when loaded.

"A Committee went out to test the bridge when it was put up, which was attempted by means of bags filled with earth. Commencing with a single row of these bags along the centre, when the load on the centre span attained 29,000 lbs., or only 11 lbs. per square foot of area, the deflection in the centre was shown by the level to be $2''\ \frac{7}{8}$ths. Increasing the load to 30 lbs. per square foot, *exclusive* of the weight of the bridge, the deflection amounted to $3''\ \frac{1}{10}$th; and with this load the longitudinal beams began to buckle and bend outwards, thereby proving its incompetency to resist compression, and bringing the tensile action into play, as will be shown by the result of the fall presently. The bridge having thus showed signs of weakness, it was recommended that it should only be subjected to the ordinary traffic of the country, for that it was not strong enough to bear heavy traffic, or any thing like the load to which all suspension bridges may at times be liable.

"It most unfortunately happened, that before this precautionary recommendation could be communicated to the civil authority residing at a distance, some grand festival took place on the water, to witness which, a crowd of natives rushed on the bridge, nearly filling the platform, and after a few minutes it gave way, and drowned nearly one hundred and fifty of them.

"Now on examination of the iron of the longitudinal beam at the point of fracture, the fibres of the iron were drawn out and very attenuated, like needles projecting, thus proving beyond all doubt that great tension must have been exerted there to tear it asunder.

"The following Table, which is similarly drawn out to that which accompanied my 'Memoir on the Resultant System,' will show that in an extreme load, whilst the chains would only be strained with a power of 8 or 9 tons per square inch, the longitudinal beams, *at the same time*, would be strained with a power of about 18 tons in the centre, per square inch; and hence the cause of weakness.

Table showing Strains on Parts of the Kubudduk Bridge with a Load entire of 112 lbs. *per Square Foot of Platform.*

Angles of oblique rods.	Natural coseecants of angles.	Natural cotangents of ditto.	Load in tons.	Horizontal tension or load × by the cotangents.	Tensions on oblique rods, or load × by coseets.	
9° 30′	6·16	6·08	3 tons per space of platform upheld by each set of ob. rods, at 112 lbs. per square foot, including traffic and weight of bridge.	Tons 18·24	Tons 18·48	Section of one set of oblique rods - 1·75 inches.
11° 10′	5·16	5·06		„ 15·18	„ 15·18	
15° 50′	3·66	3·52		„ 10·56	„ 10·98	
18° 30′	3·15	2·98		„ 8·94	„ 9·45	
21° 40′	2·71	2·52		„ 7·56	„ 8·13	
24° 30′	2·41	2·19		„ 6·57	„ 7·23	
27° 10′	2·19	1·95		„ 5·85	„ 6·57	
30°	2·	1·73		„ 5·19	„ 6·	
32°	1·88	1·60		„ 4·80	„ 5·64	
34°	1·78	1·48		„ 4·44	„ 5·34	
36° 50′	1·67	1·33		„ 3·99	„ 5·01	
39° 40′	1·56	1·21		„ 3·63	„ 4·68	
41°	1·52	1·15		„ 3·45	„ 4·56	
43°	1·46	1·07		„ 3·21	„ 4·38	
59° 30′	1·16	0·59		„ 1·77	„ 3·48	
		The rods in the centre strained five times more than those at abutments.		Tons 103·38, or total tension in centre of longitudinal beams: the section effective to resist tension being not more than 6 square inches; so that when fully loaded these beams would be strained at 17 tons per square inch.		

"Calcutta, 18th October, 1846. H. G."

Formulæ for a Suspension Bridge: links of any length and weight.

SUPPOSE the middle link is horizontal, and the number of links to be $2n+1$.

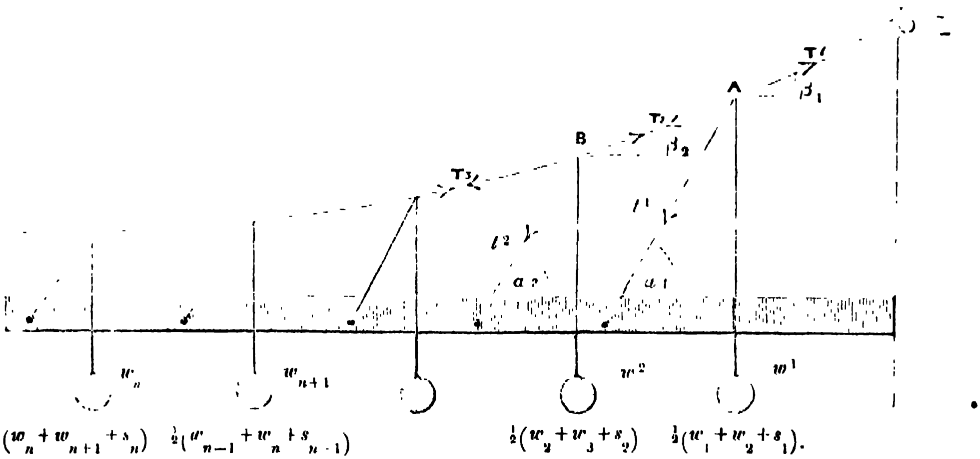
The state of equilibrium of the bridge will not be affected if we suppose the weight of each link to be divided into two equal parts and suspended from the extremities, and the link then to be supposed to have no weight. The same with the *rods.*

Let w_1 w_2 w_3 w_4 . . . . w_n w_{n+1} be the weights of the links from either pier to the *centre.*

s_1 s_2 s_3 s_4 . . . . s_n the weights of the suspending rods.

Then the problem to be solved resolves itself into one of a chain without weight, with weights suspended at the joints of the links, thus:

Fig. 1.



Let T_1 T_2 . . . . T_n T_{n+1} be the tensions of the *links.* t_1 t_2 . . . . t_n . . . . suspending rods.

We shall now deduce the formulæ of equilibrium of the points A and B, and these will lead to all the rest.

The point A is held in equilibrium by four forces, T_1, T_2, t_1, $\frac{1}{2}(w_1+w_2+s_1)$.

Resolve these forces *perpendicularly* to A B.

$$\therefore T_1 \sin.(\beta_1-\beta_2) = t_1 \sin.(\alpha_1-\beta_2) + \tfrac{1}{2}(w_1+w_2+s_1)\cos.\beta_2.$$

$$(1)\quad \therefore t_1 = \frac{\sin.(\beta_1-\beta_2)}{\sin.(\alpha_1-\beta_2)}\,T_1 - \tfrac{1}{2}(w_1+w_2+s_1).\frac{\cos.\beta_2}{\sin.(\alpha_1-\beta_2)}.$$

Resolve the four forces perpendicularly to A S.

$$\therefore T_2 \sin.(\beta_1 - \beta_2) = t_1 \sin.(\alpha_1 - \beta_1) + \tfrac{1}{2}(w_1 + w_2 + s_1)\cos.\beta_1.$$

$$(2) \quad \therefore T_2 = \frac{\sin.(\alpha_1 - \beta_1)}{\sin.(\beta_1 - \beta_2)} t_1 + \tfrac{1}{2}(w_1 + w_2 + s_1)\frac{\cos.\beta_1}{\sin.(\beta_1 - \beta_2)}.$$

In the same manner, from considering the equilibrium of B we should have

$$(3) \; t_2 = \frac{\sin.(\beta_2 - \beta_3)}{\sin.(\alpha_2 - \beta_3)} T_2 - \tfrac{1}{2}(w_2 + w_3 + s_2)\frac{\cos.\beta_3}{\sin.(\alpha_2 - \beta_3)},$$

and

$$(4) \; T_3 = \&c., \&c.$$

Substitute in (3) for T_2 from (2).

$$\therefore t_2 = \frac{\sin.(\beta_2 - \beta_3)}{\sin.(\beta_1 - \beta_2)} \cdot \frac{\sin.(\alpha_1 - \beta_1)}{\sin.(\alpha_2 - \beta_3)} \left\{ t_1 + \tfrac{1}{2}(w_1 + w_2 + s_1)\frac{\cos.\beta_1}{\sin.(\alpha_1 - \beta_1)} \right\} - \tfrac{1}{2}(w_2 + w_3 + s_2) \cdot \frac{\cos.\beta_3}{\sin.(\alpha_2 - \beta_3)}.$$

This and equations (1) and (2) lead to the requisite formulæ, which are as follows:

Tensions of Suspending Rods.

$$t_1 = \frac{\sin.(\beta_1 - \beta_2)}{\sin.(\alpha_1 - \beta_2)} T_1 - \tfrac{1}{2}(w_1 + w_2 + s_1) \cdot \frac{\cos.\beta_2}{\sin.(\alpha_1 - \beta_2)}.$$

$$t_2 = \frac{\sin.(\beta_2 - \beta_3)}{\sin.(\beta_1 - \beta_2)} \frac{\sin.(\alpha_1 - \beta_1)}{\sin.(\alpha_2 - \beta_3)} \left\{ t_1 + \tfrac{1}{2}(w_1 + w_2 + s_1)\frac{\cos.\beta_1}{\sin.(\alpha_1 - \beta_1)} \right\} - \tfrac{1}{2}(w_2 + w_3 + s_2)\frac{\cos.\beta_3}{\sin.(\alpha_2 - \beta_3)}.$$

$$t_3 = \frac{\sin.(\beta_3 - \beta_4)}{\sin.(\beta_2 - \beta_3)} \frac{\sin.(\alpha_2 - \beta_2)}{\sin.(\alpha_3 - \beta_4)} \left\{ t_2 + \tfrac{1}{2}(w_2 + w_3 + s_2)\frac{\cos.\beta_2}{\sin.(\alpha_2 - \beta_2)} \right\} - \tfrac{1}{2}(w_3 + w_4 + s_3)\frac{\cos.\beta_4}{\sin.(\alpha_3 - \beta_4)}, \ \&c.$$

$$t_n = \frac{\sin.(\beta_n - \beta_{n+1})}{\sin.(\beta_{n-1} - \beta_n)} \frac{\sin.(\alpha_{n-1} - \beta_{n-1})}{\sin.(\alpha_n - \beta_{n+1})} \left\{ t_{n-1} + \tfrac{1}{2}(w_{n-1} + w_n + s_n)\frac{\cos.\beta_{n-1}}{\sin.(\alpha_{n-1} - \beta_{n-1})} \right\} - \tfrac{1}{2}(w_n + w_{n+1} + s_n)\frac{\cos.\beta_{n+1}}{\sin.(\alpha_n - \beta_{n+1})} \qquad (\beta_{n+1} = 0).$$

Tensions of the Links.

$$T_2 = \frac{\sin.(\alpha_1 - \beta_1)}{\sin.(\beta_1 - \beta_2)} t_1 + \tfrac{1}{2}(w_1 + w_2 + s_1) \cdot \frac{\cos.\beta_1}{\sin.(\beta_1 - \beta_2)}.$$

$$T_3 = \frac{\sin.(\alpha_2 - \beta_2)}{\sin.(\beta_2 - \beta_3)} t_2 + \tfrac{1}{2}(w_2 + w_3 + s_2)\frac{\cos.\beta_2}{\sin.(\beta_2 - \beta_3)}, \ \&c.$$

$$T_{n+1} = \frac{\sin.(\alpha_n - \beta_n)}{\sin.(\beta_n - \beta_{n+1})} t_n + \tfrac{1}{2}(w_n + w_{n+1} + s_n)\frac{\cos.\beta_n}{\sin.(\beta_n - \beta_{n+1})}.$$

T_1 may be first found thus. The two forces T_1 and T_1 at the piers support the weight of roadway links and rods; let this $= W$. Hence resolving forces vertically,

$$4\ T_1 \sin.\ \beta_1 = W : \therefore T_1 = \tfrac{1}{4} W \operatorname{cosec}.\ \beta_1 .$$

and then the above formulæ will give all the t's and T's.

I.—*First Case.*

The above formulæ are entirely *general*, and *applicable to all cases.*

But we shall now *assume*, that the angles $\beta_1\ \beta_2\ \beta_3\ \ldots\ldots\ \beta_n$ diminish by equal gradations, which is the usual mode of construction, or comes to the same thing.[1]

Hence $\beta_1 - \beta_2 = \beta_2 - \beta_3 = \beta_3 - \beta_4 = \&c. = \beta_n - \beta_{n+1}$, and the preceding formulæ become very much simplified, and stand now as follows:

Tensions of Suspending Rods.

$$t_1 = \frac{\sin.\ (\beta_1 - \beta_2)}{\sin.\ (\alpha_1 - \beta_2)} T_1 - \tfrac{1}{2}\,(w_1 + w_2 + s_1)\,\frac{\cos.\ \beta_2}{\sin.\ (\alpha_1 - \beta_2)}.$$

$$t_2 = \frac{\sin.\ (\alpha_1 - \beta_1)}{\sin.\ (\alpha_2 - \beta_3)}\, t_1 + \frac{\tfrac{1}{2}\,(w_1 + w_2 + s_1)\cos.\ \beta_1 - \tfrac{1}{2}\,(w_2 + w_3 + s_2)\cos.\ \beta_3}{\sin.\ (\alpha_2 - \beta_3)}.$$

$$t_3 = \frac{\sin.\ (\alpha_2 - \beta_2)}{\sin.\ (\alpha_3 - \beta_4)}\, t_2 + \frac{\tfrac{1}{2}\,(w_2 + w_3 + s_2)\cos.\ \beta_2 - \tfrac{1}{2}\,(w_3 + w_4 + s_3)\cos.\ \beta_4}{\sin.\ (\alpha_3 - \beta_4)}, \ \&c.$$

$$t_n = \frac{\sin.\ (\alpha_{n-1} - \beta_{n-1})}{\sin.\ (\alpha_n - \beta_{n+1})}\, t_{n-1} + \frac{\tfrac{1}{2}\,(w_{n-1} + w_n + s_{n-1})\cos.\ \beta_{n-1} - \tfrac{1}{2}\,(w_n + w_{n+1} + s_n)\cos.\ \beta_{n+1}}{\sin.\ (\alpha_n - \beta_{n+1})}.$$

If it is considered desirable to have the tensions of the suspending rods pretty nearly the same, we may make an *approximation* to this by choosing the angles so that this shall *exactly* be the case, on the supposition of the weights of the links and rods being small when compared with the weight of the *loaded* bridge.

By the above this leads to the condition, that the co-efficients of $t_1\ t_2\ \ldots$ each equal unity.

$$\therefore \alpha_1 - \beta_1 = \alpha_2 - \beta_3,$$

$$\alpha_2 - \beta_2 = \alpha_3 - \beta_4,$$

$$\ldots = \ldots$$

$$\alpha_{n-1} - \beta_{n-1} = \alpha_n - \beta_{n+1}.$$

$$\therefore \alpha_1 - \alpha_2 = \beta_1 - \beta_3 = 2\,(\beta_1 - \beta_2)$$

$$\alpha_2 - \alpha_3 = \beta_2 - \beta_4 = 2\,(\beta_1 - \beta_2).$$

$$\ldots\ldots$$

$$\alpha_{n-1} - \alpha_n = \beta_{n-1} - \beta_{n+1} = 2\,(\beta_1 - \beta_2)$$

$$\therefore \alpha_1 - \alpha_n = 2\,(n - 1)\,(\beta_1 - \beta_2).$$

$$\therefore \alpha_1 - \alpha_n = (2n - 2).\frac{\beta_1}{n} = 2\beta_1 - \frac{1}{n}\,(2\beta_1).$$

These formulæ show that the angles of inclination of the rods must increase continually from the centre towards the piers by a constant angle, equal to twice the constant increase in inclination of the links to the horizon.

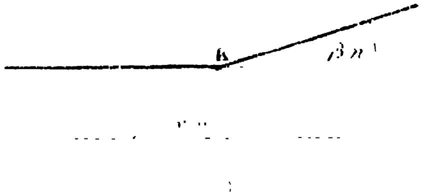
---

[1] The usual mode is to make the *tangents* diminish by equal quantities; but the angles are always sufficiently small to make this the same as the *angles*, diminishing by equal gradations.

The angle α_1 or α_n (*which* of them we please) may be chosen of any value without violating the *above* conditions.

It is best, however, to chose α_n such as to make the tensions t_n and T_{n+1} as nearly proportional to the thickness of iron as possible.

If the quantity of iron in horizontal link and the suspending rods be the same, t_n and T_{n+1} should be nearly the same: and therefore



$$\alpha_n = 2\beta_n = \frac{2}{n}\,\beta_1,$$

or a little *less*, $\because$ of the *weight* at K.

The equations in the preceding pages, then, lead in the case of a *double central link* to the following very APPROXIMATE values of the angles.

$$\beta_{n+1} = 0,\ \beta_n = \frac{1}{n}\beta_1,\ \beta_{n-1} = \frac{2}{n}\beta_1,\ \ldots\ldots\ \beta_2 = \frac{n-1}{n}\beta_1,$$

$$\alpha_n = \frac{2}{n}\beta_1,\ \alpha_{n-1} = \frac{4}{n}\beta_1,\ \ldots\ldots\ \alpha_2 = \frac{2n-2}{n}\beta_1,\ \alpha_1 = 2\beta_1.$$

The angles α should be a *little smaller* than these if we take the weights into account. But the numerical calculations will give the exact values.

II. *Second Case.*

Suppose the links are equally inclined to each other in succession, *as before*, with the exception of the last but one and the central one:

i. e. Suppose $\beta_1 - \beta_2 = \beta_2 - \beta_3 = \ldots\ldots = \beta_{n-1} - \beta_n$; but that $\beta_n - \beta_{n+1}$ *differs* from these.

Then the formulæ of page 142 will all be true except the *last*, which will stand as it did in page 141.

The conditions that the rods should be strained nearly alike lead to the following:

$$\alpha_1 - \beta_1 = \alpha_2 - \beta_3, \qquad \therefore\ \alpha_1 - \alpha_2 = \beta_1 - \beta_3 = 2\,(\beta_1 - \beta_2),$$

$$\alpha_{n-2} - \beta_{n-2} = \alpha_{n-1} - \beta_n. \qquad \therefore\ \alpha_{n-2} - \alpha_{n-1} = \ldots\ldots = 2\,(\beta_1 - \beta_2)$$

$$\alpha_1 - \alpha_{n-1} = (2n-4)\,(\beta_1 - \beta_2)$$

and

$$\frac{\sin.\,(\beta_n - \beta_{n+1})}{\sin.\,(\beta_{n-1} - \beta_n)}\cdot\frac{\sin.\,(\alpha_{n-1} - \beta_{n-1})}{\sin.\,(\alpha_n - \beta_{n+1})} = 1.$$

This last leads to the following equation (since the *angles* are all small, and $\beta_{n+1} = 0$).

$$\frac{\beta_n}{\beta_{n-1}-\beta_n} = \frac{\alpha_n}{\alpha_{n-1}-\beta_{n-1}}.$$

$$\therefore \alpha_{n-1} = \beta_{n-1} + \frac{\alpha_n}{\beta_n}\left\{\beta_{n-1}-\beta_n\right\}$$

$$= \beta_n + \left(\frac{\alpha_n}{\beta_n}+1\right)(\beta_{n-1}-\beta_n)$$

$$= \beta_n + \left\{\frac{\alpha_n}{\beta_n}+1\right\}(\beta_1-\beta_2).$$

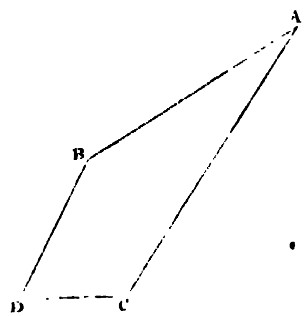
$$\therefore \alpha_1 = \beta_n + \left\{\frac{\alpha_n}{\beta_n}+2n-3\right\}(\beta_1-\beta_2).$$

β_1 β_2 α_n β_n being selected with reference to the data of the bridge, α_1 is known by this formula, and $\therefore$ α_2 α_3 . . . . α_{n-1} by the formulæ of the preceding page.

J. H. O.

Note by Professor Walker, Oxford.

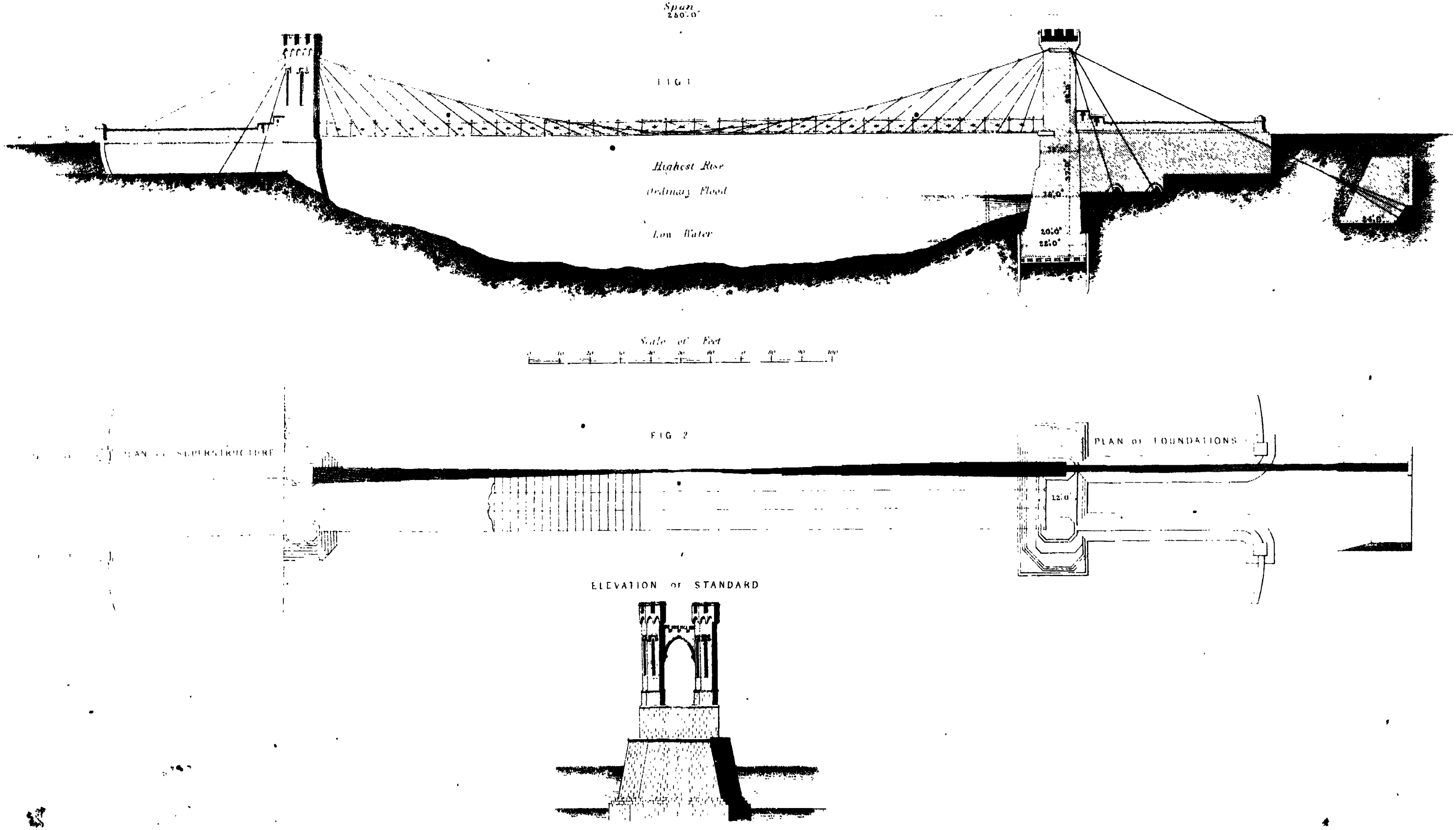
Is there not a very important element omitted, viz., the necessity that the whole of the *roadway* must be perfectly *rigid?* If it is not so, any given portion as C D would collapse or double up. The introduction into the system of a rigid roadway, which must under all circumstances of loading remain horizontal, will, I suspect, entirely alter the process of calculation. It is no longer a flexible system which can assume its *own* form.



It may be doubted also whether any advantage will be gained by this construction. There may be a saving in the weight of central links, but there must be an increased strength in the *roadway*.

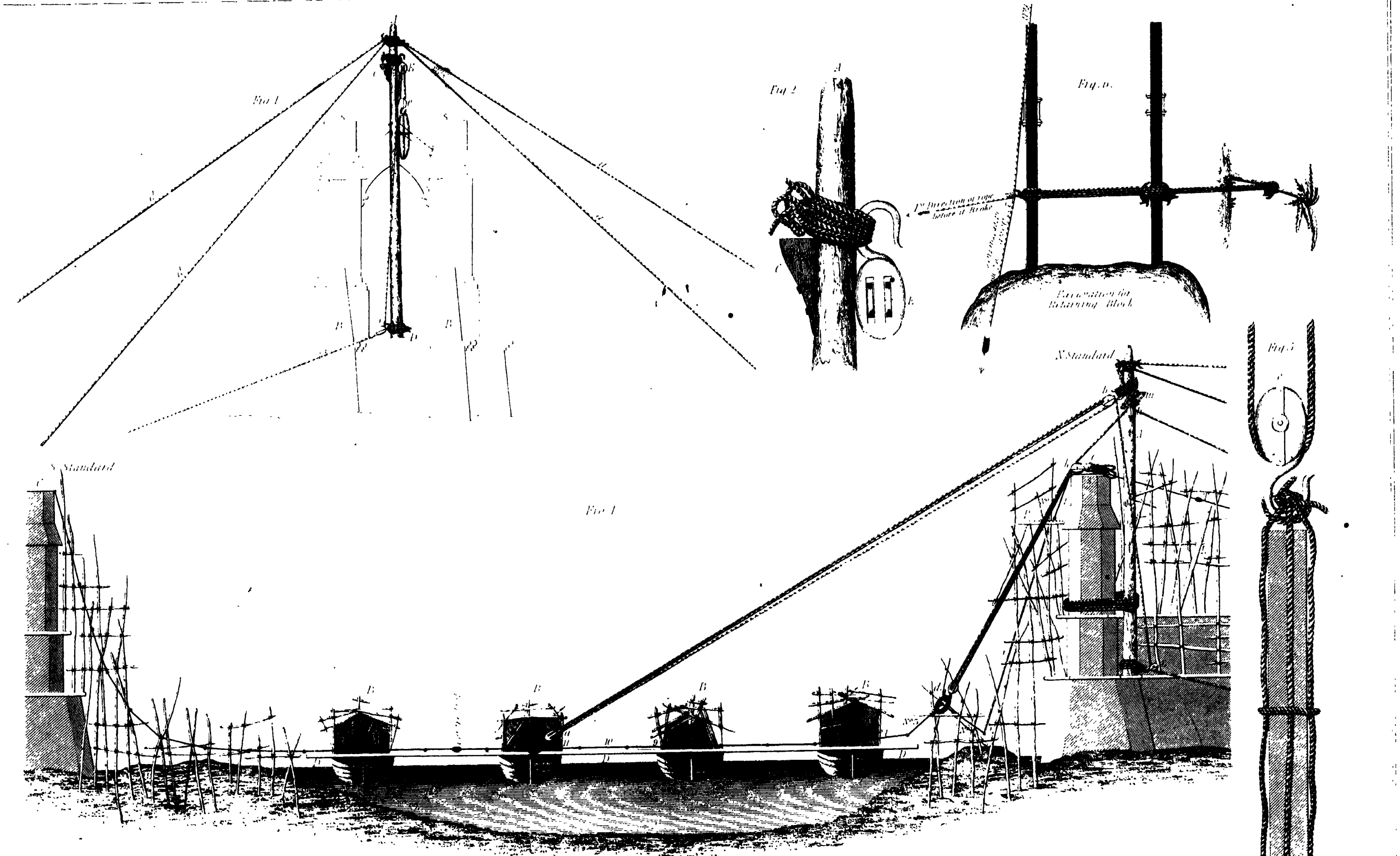
R. W.

Plan Elevation and Section of the Tension Bridge;
erected over the
BALLEE KHÂL NEAR CALCUTTA.



W. Sutherland delt.

J. Hawksworth sculp.



A	Derrick
B.B.	Native boats
C.C.	Standards
D	Platform on boats
P	Platform for linking Nos 1 & 2
T	Back Chain

a Double Block lashed to bolt connecting Nos 11 & 12 links
b Do do lashed to derrick
c Snatch block at foot of Do
d Treble block lashed to bolt connecting Nos 2 & 3 links

k Treble block lashed to rear bolt of Tower link
h Snatch block lashed to Derrick
m Wooden cleat spiked to Do
L Log supporting Back Chain
r Small rope attached to No 2 link and pulled by Classes on Platform P

Fig 5
Showing bamboo framing
to support the Back Chains

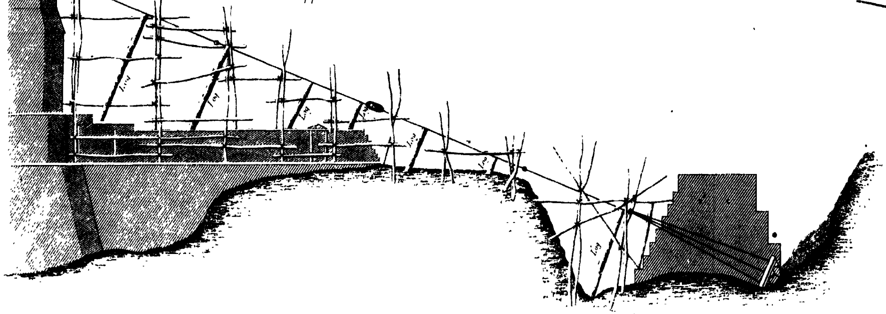


Figure
showing the method of hauling up
and slinging the longitudinal beams
and oblique rods

Fig 7

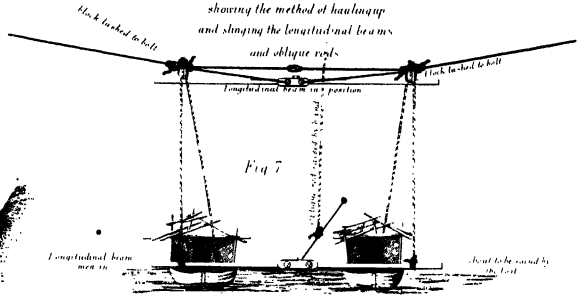


Fig 8
showing method of loosening
centre link

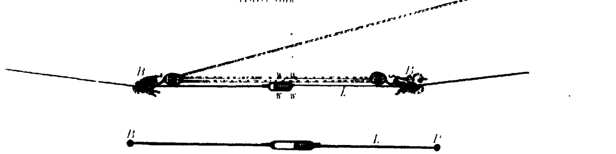


Fig showing centre link after
wedges were forced out

Fig 9

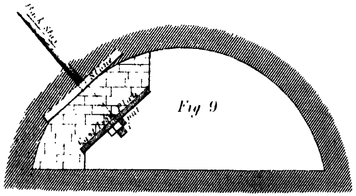
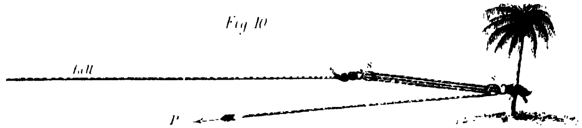
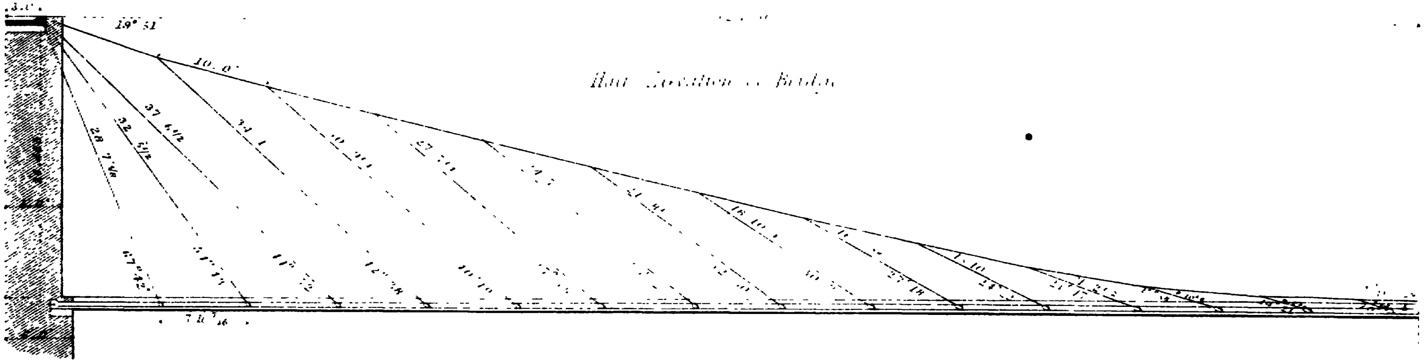
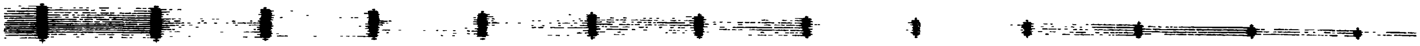


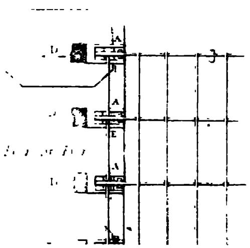
Fig 10

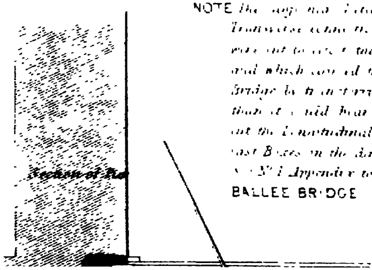


BALLEE KHAL BRIDGE



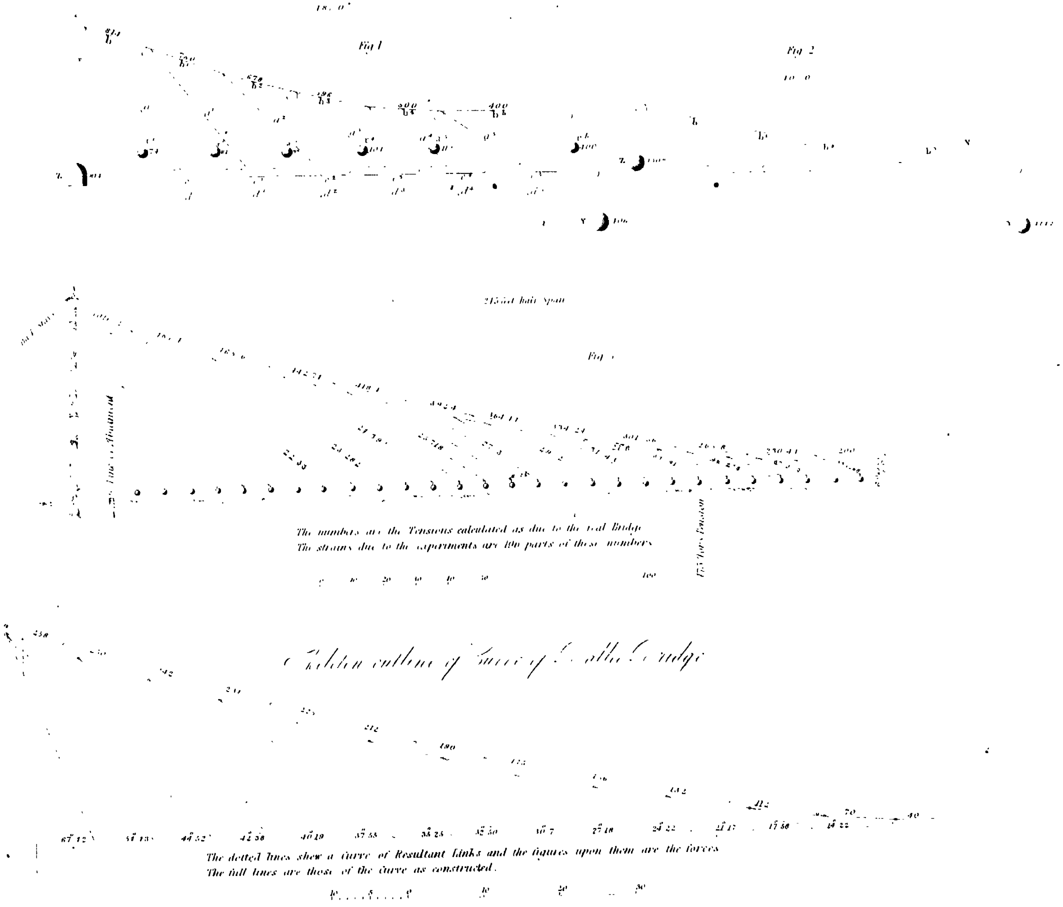






NOTE the [illegible] show the places where the Transverse connections of the Longitudinal Beams were cut to effect the repair of the injured Beam and which caused the fracture in the centre of the Bridge by throwing to that point more tension than it could bear. When the Bar and Bolts were cut the Longitudinal Beams could freely move in the cast Boxes in the direction shown by the Arrows. See No 1 Appendix to Report on the failure of the BALLEE BRIDGE

Sketches illustrative of Three Experiments undertaken to test the Taper Chain Resultant System of Iron Suspension Bridges.

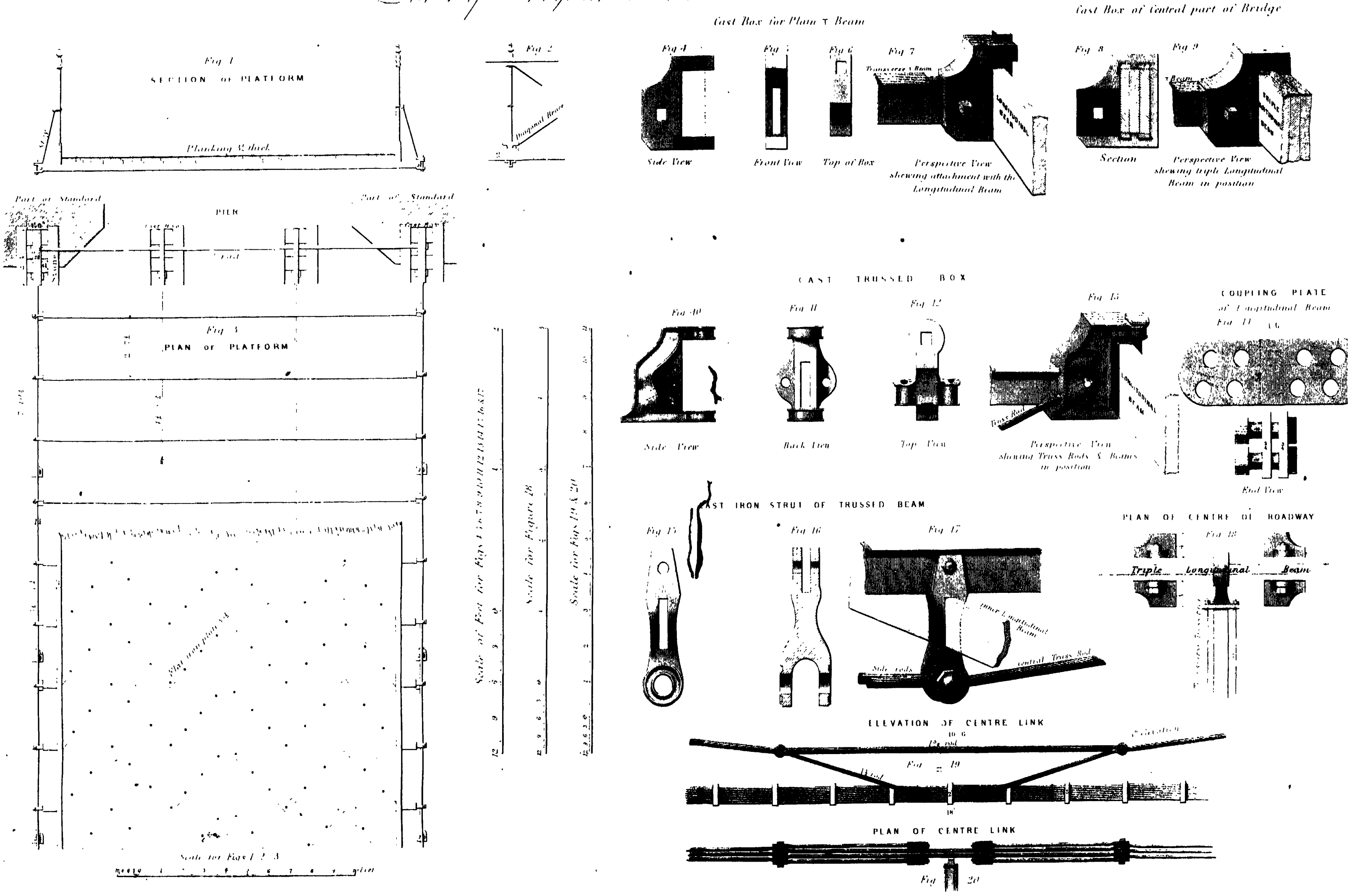


F. W. Cumberland del.

B. R. Davies, fc.

London John Weale Architectural Library, High Holborn 1847.

Details of Bridge constructed over the Tolly's Nullah, Calcutta.



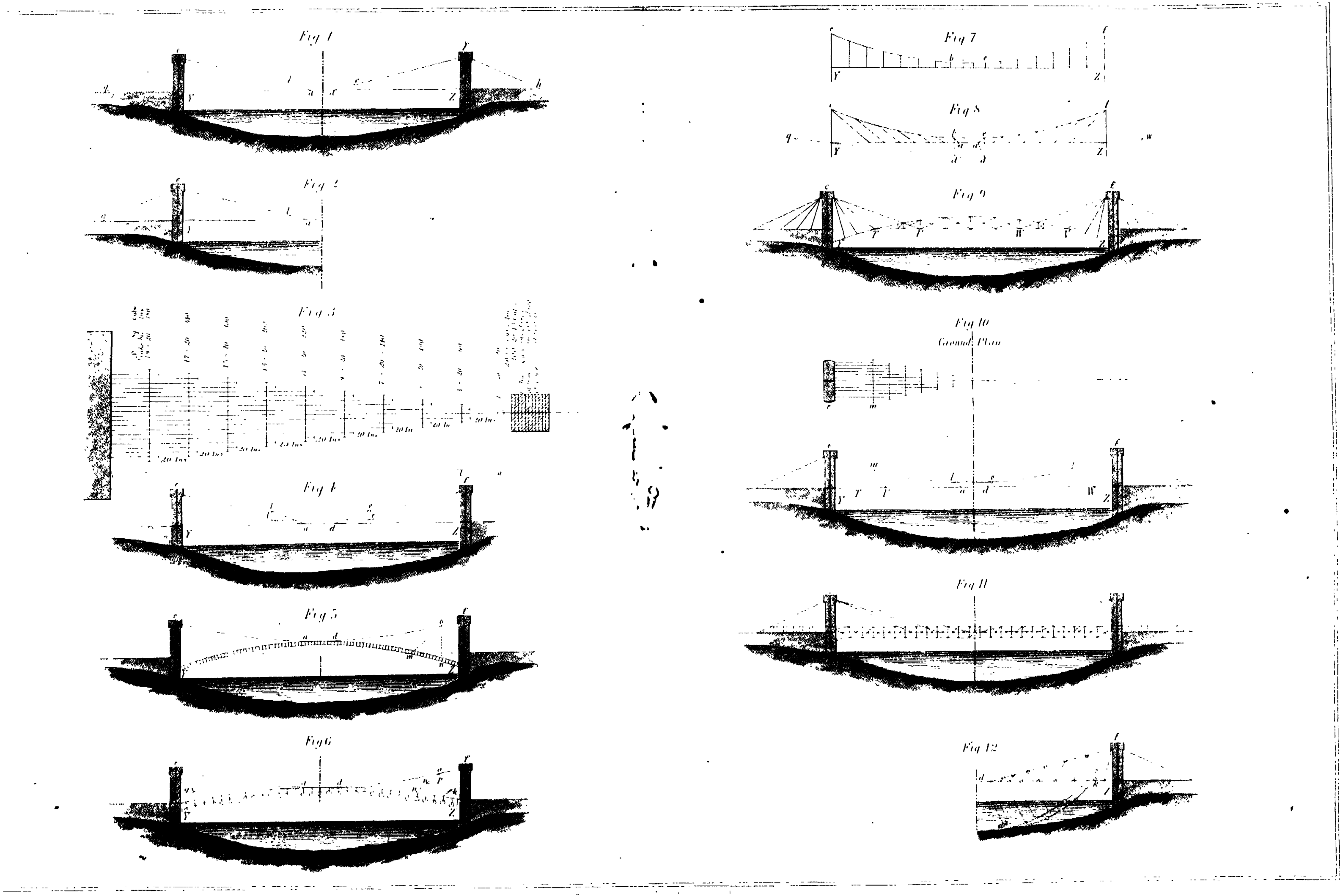


Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Ground Plan
Fig 11
Fig 12

figs. 5, 6, and 7. A saving of labour in the construction is also gained without materially weakening the parapet.

A merlon of 7 feet is left between each embrasure.

Fig. 8 shows an elevation on the centre line of the embrasure, assuming the height of the genouillère to be 2 feet 1 inch, to which dimension all the garrison carriages in the Service are constructed.

It might not be necessary to have mantlets for each embrasure, as they would be kept in store until required, and then only issued for the service of those guns which were likely to be employed, and exposed to a heavy fire.

The sides of the exterior opening of the embrasures should be faced with ashlar, as well as 3 feet of the face of the escarp on each side of it, and they might have a slope of about 1 in 4 at the outer extremity, diminishing to nothing opposite the traversing point, to assist in the removal of the smoke.

As the exact distance of the traversing point from the escarp, or the length which the muzzle of the gun should project into the exterior, in order that the smoke may not be retained to any injurious extent after the discharge, can only be determined by experiment, the dimensions which I have assumed may not be sufficient, but any alteration in them will not affect the general principles of the construction, even though it may be found necessary to enlarge the exterior opening by altering the direction of the outer faces.

An embrasure may be constructed on this principle, admitting of a traverse of 60°, and presenting an external opening of only 5 feet; the traversing point being fixed at 3′ 6″ from the line of the escarp.

From such a battery, the fire of 24 guns might be concentrated on a point 122 yards in front of the centre of the line of the battery.

Where only a small angle of traverse is required, the external opening becomes smaller, and the angle at the shoulder more obtuse.

As a final protection from vertical fire, an arch may be thrown over the *interior* part of the embrasure, in those situations where it may be deemed necessary.

H. N. Penrice,
Lieutenant, Royal Engineers.

Corfu, August 30th, 1846.

XIV.—*Railways.* *By* G. Drysdale Dempsey.

(Concluded from vol. viii. page 155.)

SECTION V.

STATIONS AND THEIR FITTINGS, LOCOMOTIVE POWER AND ALL ARRANGEMENTS BELONGING THERETO, CARRIAGES, &c.

The several points for consideration in the design and arrangement of railway stations are too various to admit of any very minute classification. In their general features only can any resemblance be recognised, or any rules made applicable. And yet in this department of his vocation the Engineer finds a large demand upon his discretion, and feels that much of the current economy of the line will depend upon the conveniences or inconveniences which his arrangement of the stations, and their several adjuncts, may provide. The nature and magnitude of the traffic likely to occur, and the peculiarities of site and locality for the intended station, involve the main considerations, and must determine most of the details required. The site will be determined by the contiguity of the town or place to be accommodated, facility or economy of purchase, &c.; and, besides these, the question of relative levels arises, and deserves most especial regard. Indeed the commercial value of the stations may be said to be made or marred by the facility or the difficulty of communicating with the adjoining thoroughfares. Whether the station be above or below the neighbouring level, a similar amount of expense and trouble will be incurred in transferring the luggage, and of inconvenience in transferring the passenger traffic. In some cases, as where a railway is permitted to approach a town only upon a viaduct, this great difficulty is necessarily encountered, and must be provided for by the best expedients which are available. If the level of the rails be only about 4 feet above that of the approach road, the difference is readily made up by steps for the passengers, while it offers convenience in transferring the luggage from the platform direct into carts and waggons. A few additional feet beyond this may be accommodated by extra steps, and by

employing 'shoots' or troughs inclined from the one level to the other; but if the merchandise usually carried be of a bulky and weighty character, the goods department is preferably removed to such a distance that an ascending approach road may be formed. Any difference of levels may be accommodated by this expedient, provided such a length of road can be obtained as will allow the ascent by an easy gradient; but as the goods department is in such cases necessarily removed farther from the town, and from the passenger department, other inconveniences arise which it is very desirable to obviate. Where such approaches cannot be had, and the entire difference of levels must be provided for in a very limited space, it becomes necessary to adopt some mechanical means of raising and lowering the goods, and to provide stairs or steps for the passengers. An example of the kind of hoisting machinery which may be used in such cases will be found among the accompanying Plates, and hereafter described. The examples of stations which have been selected to illustrate these Papers are such as embrace the leading peculiarities of the buildings:—the arrangement of rails, turn-plates, &c., &c., can be readily described, but would have required many more Plates for their exhibition. The two terminal stations shown on Plates XXXIII. and XXXIV. are those erected upon the London and Blackwall Railway, the western end of which is supported on a viaduct, while the eastern is somewhat below the level of the Brunswick Wharf. Plate XXXIII. represents the latter, or Blackwall terminus. Fig. 1 is a general or 'block' plan of the building, and shows the arrangement of the rails. The station is adapted to provide for four lines of way, three of which are shown on fig. 1. On entering the station, the left-hand or 'down' line diverges into two branches, the northern one of which is connected with the main line by a switch, and is intended for the reception of spare carriages. Two turn-plates are fixed on each branch of the down line, and are placed obliquely, there not being sufficient width to place them at right angles. By these turn-plates carriages may be transferred from the main down line to the siding, and *vice versâ*. The switch shown connecting them should have such a tongue as may be usually wholly removed from the main line, and laid in connection with it only while in use; otherwise the serious objection would exist of running the down trains *against* the points of the switch, an arrangement which, as already described under 'Crossings,' is always fraught with danger. The southern or 'up' line runs uninterruptedly until stopped against the building. Fig. 2 is an external elevation of the

building and one of the side walls or screens, the other being omitted for want of room. These walls support one side of the outer bay of roofing, the other ends of the principals being carried upon light iron girders, supported on columns of the same material. The entire roof consists of two bays or spans, each about 28 feet span. Fig. 3 is a plan of the building, the ground floor of which contains a booking office, 63 feet 2 inches long by 30 feet wide, a ladies' waiting-room, 25 feet 8 inches by 17 feet 8 inches, a gentlemen's waiting-room, 19 feet 7½ inches by 17 feet 9 inches, with suitable conveniences, an entrance hall, two rooms for the police, and a spacious staircase leading to the upper floor. The foundation plan of the building is indicated by dotted lines. Figs. 4 and 5 are cross sections of the building. Figs. 6 to 16 inclusive show the roof in detail, which consists of T iron rafters and struts, and round tie and suspension rods. The feet of the rafters are received in cast iron shoes, into which the ends of the tie-rods are also secured with gibs and keys. Angle iron purlins are riveted on the rafters, and are filled with wooden battens to receive the slates. The stationary steam engines by which the down trains are propelled are situated at a short distance from this terminus, and the carriages are detached from the rope while in motion, and with sufficient impetus to carry them forward into the station. The rails ascend towards the station, and thus the carriages in departing descend, by their own gravity, to the point where they are connected to the rope. The arrangements for the trains on this line, although frequently described, and probably well known, are well adapted for carrying on the traffic of a short line of railway worked by stationary power, and deserve a brief description in this place. The line is nearly throughout its entire length carried upon brick arches (as described in Section III.), and without facilities for widening it at the intermediate stations. Hence the carriages destined to accommodate these stations are necessarily stopped on the main lines. The whole line being less than four miles in length, and there being five or more stations in that length, it would evidently involve a tediousness amounting almost to an impracticability to arrest the entire train by stopping the motion of the rope at each of these places. And of course similar delays and infrequency of trains would be occasioned by dispatching the carriage for each station separately, and awaiting its arrival before dispatching the next. The manner in which these objections are obviated is as follows:—The carriages are started in the same order in which the stations are situated; that is, the first carriage is intended to traverse the whole

line, and proceed to the other terminus; the second carriage is intended to stop at the most distant of the intermediate stations; the third carriage at the next station, and so on; the hindermost carriage being intended to proceed the shortest distance, and to stop at the first of the intermediate stations. Each carriage, or set of carriages, intended for each station, being attached to the rope by a peculiar clutch or grip (which will be found hereinafter described), the signal to start the engine at the other end of the line is conveyed by means of the electric telegraph, and the whole train then starts. When approaching the first of the intermediate stations, the guard in attendance on the carriage for that station releases the rope from the grip, and the carriage runs onward, by the momentum acquired, into the station; the carriages being further provided with brakes to be used when necessary. Meanwhile the train has proceeded forward, and when approaching the second station, the carriage for that station is detached in a similar manner. In this way all the carriages for intermediate stations are left as the train proceeds, and those destined for the terminus only arrive there. In returning, the carriages being all standing at their respective stations, are separately connected with the rope (then in a quiescent state), and from each station a signal is passed to the other terminus, by which the engine-man is informed when all the carriages are connected and ready to be started. The starting of the rope, of course, moves all the carriages forward simultaneously, and each arrives at the terminus separately, that from the nearest station coming in first, and the others in succession, and each being disconnected from the rope as it approaches the terminus. It is evident that this system could not be applied without some ready and unerring means of conveying signals rapidly, such as the electric telegraph affords.

Plate XXXIV. represents the London terminus of this railway, which is supported on brick arches. The Plate shows the building only adapted for the entrance and departure of passengers. The goods department is conducted at some distance from this building, and contiguous to the Minories, where also the stationary engines for propelling the up trains are situated, the line being laid with a slight descent towards them. Fig. 1 is a front elevation; fig. 2 a longitudinal section, taken on the line A A on the plan; fig. 3 a plan; and fig. 4 a cross section of the building. The entrance hall and booking offices occupy a space 32 feet 4 inches by 31 feet 6 inches, and are lighted by three sky-lights. The waiting hall, 58 feet by 56 feet 8 inches, is divided into a first

and second class by the arrival stairs, which are about 10 feet in width, and divided by short landing-places into three easy flights. One line of rails runs along over the waiting hall and on each side of the arrival stairs, being supported on iron girders carried upon columns, shown on the longitudinal section and on the plan. The railway is terminated by massive abutments of brick-work, which divide the booking offices from the waiting halls. The railway is covered by a wooden roof in two bays or spans, and is also enclosed on the sides with corrugated sheet iron, as far as the Minories station. On arriving at this terminus, the passengers alight from the carriages, and proceed on the platform on either side of the arrival stairs, and then turn to the right or left, and depart down the stairs over the booking offices and on each side of the entrance hall.

Plate XXXV. represents a commodious arrangement for a small station, comprehending a booking office 20 feet by 33 feet, two rooms for the superintendents, and separate conveniences for the passengers. The building is on one floor only, and constructed chiefly of wood framed and boarded; the foundation walls and chimneys only being of brick-work. Fig. 1 is an elevation towards the railway; fig. 2 the road elevation, having a convenient portico projecting upon four pairs of wooden columns; fig. 3 is a plan; fig. 4 half a longitudinal section, taken on the line E F on the plan; fig. 5 is a half plan of the framing of the roof; fig. 6, cross section on the line A B on the plan; and fig. 7 another cross section, and taken on the line C D on the plan.

Plate XXXVI. shows another station, adapted for a moderate passenger traffic, and having more conveniences than that shown on Plate XXXV. It comprises a general waiting-room and booking office, 34 feet 8 inches by 17 feet 2 inches, convenient offices for the passengers, besides lamp and store-room, and a kitchen and sitting-room, with closets for the superintendent, all on the ground floor, and has also four rooms on the upper floor, two of which may be allotted to the superintendent or clerk, and the other two to the use of the porter. In this Plate, fig. 1 is a general plan, to a scale of 32 feet to an inch, and shows the platforms, each 120 feet long and 12 feet wide; fig. 2 is an elevation of the building; fig. 3 a plan; fig. 4 a cross section, showing the station building on one side, and the waiting shed on the other, and the line roofed over between them; fig. 5 is a longitudinal section of the roofing; and fig. 6 a plan of the rooms on the upper floor, the intermediate roofing of the central part being omitted to insert the general plan, fig. 1. Stations similar

XII.—*On Suspension Bridges. By Captain* Harness, *R. E.*

Weston under Pen-y-ard, 11th April, 1846.

My dear Denison,

In noticing the proceedings of the last general meeting of the Chester and Holyhead Railway Company, some of the newspapers have printed a Report by Mr. Robert Stephenson on the hollow tube bridge by which he proposes to cross the Menai Strait, and in that Report the following interesting paragraphs occur.

"The injurious consequences attending the ordinary mode of employing chains in suspension bridges was brought under my observation in a very striking manner on the Stockton and Darlington Railway, when I was called upon to erect a new bridge for carrying the railway across the River Tees, in lieu of an ordinary suspension bridge, which had proved an entire failure.

"Immediately on opening the suspension bridge for railway traffic, the undulations into which the roadway was thrown, by the inevitably unequal distribution of the weight of the train upon it, were such as to threaten the instant downfall of the whole structure.

"These dangerous undulations were most materially aggravated by the chain itself, for this obvious reason—that the platform or roadway, which was constructed with ordinary trussing, for the purpose of rendering it comparatively rigid, was suspended to the chain, which was perfectly flexible, all the parts of the latter being in equilibrium. The structure was therefore composed of two parts, the stability of the one being totally incompatible with that of the other; for example, the moment an unequal distribution of weight upon the roadway took place, by the passage of a train, the curve of the chain altered, one portion descending at the point immediately above the greatest weight, and consequently causing some other portion to ascend in a corresponding degree, which necessarily raised the platform with it, and augmented the undulation.

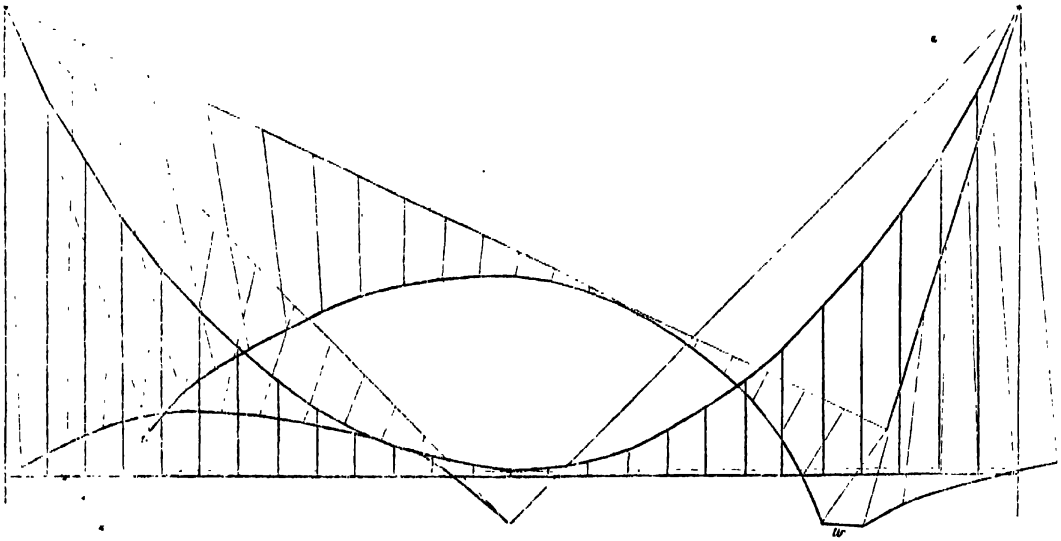
"So seriously was this defect found to operate, that immediate steps were taken to support the platform underneath by ordinary trussing; in short, by the erection of a complete wooden bridge, which took off a large portion of the strain upon the chains. If the chains had been wholly removed, the substructure would have been more effective; but as they were allowed to remain, with the view of assisting, they still partook of these changes in the form of the curve, consequent upon the unequal distribution of the weight, and eventually destroyed all the connections of the wooden

frame-work underneath the platform, and even loosened and suspended many of the piles upon which the frame-work rested, and to which it was attached."

These remarks induced me to consider whether any assistance can really be derived from chains applied in the usual manner, when the stiffness of the platform, to the extent required for framed bridges, is one of the conditions to be fulfilled.

An ordinary suspension bridge consists of two principal parts, and if stiffness be required, each should assist the other. If the platform alone were able to bear the greatest weight to which it could be exposed without flexure, no strain could be thrown upon the chains; but the platform having less strength than this, the force necessary to prevent the fracture, or excessive flexure of the platform, is to be derived from the chains. It may safely be assumed, that the weights of the chains and platform are insignificant in comparison with the loads passing over the latter, for the effect of their weight is to increase the stiffness of the bridge.

If the whole bridge be equally loaded, there is no tendency given to the chains to alter their curvature, and each bay of the platform, or interval between the suspending pieces which connect it with the chains, has only to bear the weight upon it. But if one part of the bridge be loaded, the tendency to sink at that part can only be resisted by the stiffness of the platform: if the platform and chains were equally flexible, and the ends of the platform at liberty to move, they would assume forms similar to those below, varying with the position of the load.



When one part only of a suspension bridge is loaded, the effect of the load is to deflect the platform, and to depress, to an equal extent, the chain immediately above the load; but one part of the chain cannot be depressed without tending to raise another part: if the load be near the middle, very nearly the whole of both halves of the chain endeavours to rise; if the load be towards one end, the longer section of the chain receives a tendency to rise, the other to fall.

The suspending pieces from the parts of the chain which receive a tendency to rise, act upon the under side of the platform, tending to deflect it upwards; and if the platform be stiff enough to resist this action, the structure undergoes no change. If, then, the platform be tolerably rigid, the effect of any partial weight is to expose the under side of the platform to a number of equal pressures, tending to deflect the platform upwards, the whole amount of pressure being equal to the passing weight.

If the end a be retained in its position, and the part of the platform from a to w be too stiff to permit the part of the chain above it to rise, the remaining portion must retain its position, and support the platform. The part $a\,w$ should therefore be sufficiently stiff to bear a pressure equally distributed along its under side, equal to the same proportion of the weight w that the length $a\,w$ is of the length of the bridge. It is necessary then to determine the proportion of the full load of the bridge with which the tendency to bend the platform is greatest, and the platform must be stiff enough to resist its action.

Let w be the greatest load to which the bridge, when occupied throughout, can be exposed;
x, the length loaded;
$\mathrm{L}-x$, the part unoccupied.

Then, assuming that the load is in proportion to the space occupied,

$\mathrm{L} : w :: x : \frac{w\,x}{\mathrm{L}}$, the load on the bridge;

and,

$\mathrm{L} : \mathrm{L}-x :: \frac{w\,x}{\mathrm{L}} : \frac{(\mathrm{L}-x)\,w\,x}{\mathrm{L}^2}$, the equally distributed strain to be borne without extraordinary flexure by the part unoccupied; and the effect of this strain will be greatest when its product with $(\mathrm{L}-x)^3$, the cube of the length over which it acts, is a maximum; that is, $x\,(\mathrm{L}-x)^4$ must be a maximum, or, $x = \frac{1}{5}\,\mathrm{L}$.

If the foregoing observations be correct, the platform of a suspension bridge

should be sufficiently stiff to bear, equally distributed over four-fifths of the span, a strain equivalent to four twenty-fifths of the load which it would be necessary to provide against, and to consider distributed over the whole span, if a framed bridge were used. And as the effect to produce deflection is as the weight and the cube of the span, it may be said, that it is only necessary to give a suspended platform one-twelfth the strength of an independent platform. Assuming the case of a simple solid beam across an opening, five-ninths of the depth, or eleven-twelfths of the breadth, may be saved, or some less proportion may be taken from each of these dimensions, by adopting suspension chains; or a beam of the same section will be equally rigid if applied to an opening 76 per cent. wider, and exposed, in consequence, to a load in the same proportion greater. This result must not, however, be supposed to apply to beams strengthened by tension bars: when a tension bar is applied, its dip is always so small a proportion of the length of the beam, that the extension of the bar, when a strain falls upon it, may allow an important amount of deflection.

The figure suggests the advantage to be derived from making each half of the platform of a suspension bridge serve as a secure tie to one-half of the chain, and as a strut to the other half. And if the views adopted in the above be true, the framing of the platform should be arranged to resist a tendency to deflect upwards.

Very sincerely yours,

H. D. HARNESS.

XIII.—*On Embrasures.* *By Lieut.* PENRICE, *R. E.*

THE practice of gunnery, both naval and military, having arrived by recent improvements to a high degree of accuracy, it becomes desirable to obtain, if possible, a corresponding increase of cover and protection for the guns, and the men working them, from the effects of a well-directed fire, allowing them at the same time to use their own to the best possible advantage.

An embrasure is the term which is applied to designate the opening or cut in a parapet for the purpose above mentioned.

In order to arrive at the form which will generally be best adapted for permanent works, either inland or on the coast, it will be necessary to state the various qualifications that will be required of them, bearing in mind at the same time their relative importance, so that, in the construction, each may have its due share of consideration.

In a general point of view, embrasures should be sufficiently solid in their form to withstand the effects of a counter-fire from the exterior, as well as the explosion of the charge of the piece which fires through them.

They must afford as much cover as possible to the guns, and to the men working them, from external fire, both direct and enfilade.

They should admit of a good traverse, enabling each gun to see over a wide extent of country, in order to be able to concentrate the effect of as many as may be required on any single object.

At the same time, they should not occupy more of the parapet than is sufficient for the working and *matériel* of each piece, that the front may present as numerous a battery as possible.

A free passage should be afforded to the exit of the smoke, that it is not retained in the embrasure after the discharge.

The angles which are exposed to fire should be obtuse, and in those directions in which sufficient depth of resistance cannot conveniently be given

to oppose the direct force of a shot, the face which is exposed should present an oblique surface, so as not to receive the whole force of the shot.

These will be sufficient to guide us in the construction of a general form, the details of which can be then completed in manner best suited to carry out the requisite qualifications.

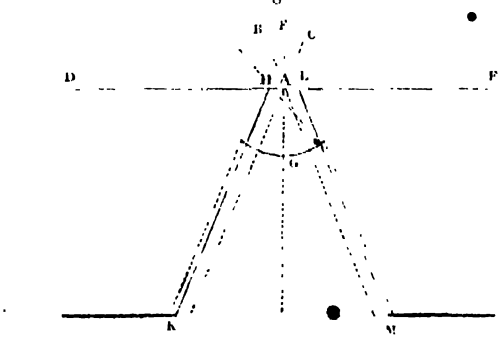
Let it be required to construct an embrasure in the face of a work to answer the above conditions.

The embrasure to be perpendicular to the direction of the face, and to admit of a traverse of 45°, for a 32-pounder gun, (Monk's construction.)

Let D E, fig. 1, represent the line of the escarp (which we will suppose to be finished as high as the terreplein of the work), and let F G, perpendicular to D E, represent the central line of fire, on each side of which the gun is to traverse $22\frac{1}{2}$°.

Our first object will be to determine the point in F G on which it is to traverse.

Fig. 1.



We will first assume it to be at A, at the intersection of the outer face D E with F G, and let the ∠ B A C=45° represent the angle of traverse. Draw H K, L M, parallel to C A, and B A, produced respectively, and at a distance from them equal to half the width of the gun and carriage (to allow sufficient room for traversing to the desired extent); these will represent the sides of the embrasure. With centre A and dist. A G=$3\frac{1}{2}$ feet, describe the genouillère, allowing the muzzle of the gun to project clear of H L, when it is run up.

In this case, the gun and the men working it will be well protected from the effects of enfilade fire by a parapet 13 feet in thickness.

The exterior aperture (H L) is as small as possible, and at first no shot from the exterior, unless directed upon the opening, can enter into the embrasure.

On the other hand, it is open to the entrance of many shot coming from a position considerably removed from the extreme right and left limits of its own range; which would either enter direct into the interior, or would ricochet from the faces H K and L M, at very favourable angles, to the annoyance of those working the guns.

The shoulders at H and L are acute, and are not sufficiently solid to withstand the effect of the shot striking them, so that the exterior opening would soon be enlarged, and the form of the embrasure destroyed.

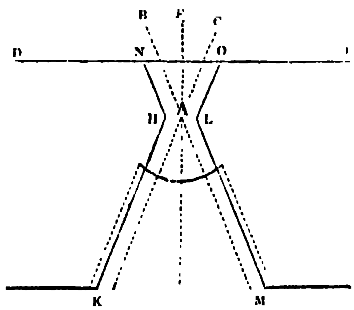
Neither is there sufficient depth of resistance from the genouillère to the exterior, so that both the gun and the men would soon be entirely exposed. The interior opening of the embrasure would be so large that the parapet would be considerably weakened, and in order to accommodate this angle of traverse it would be necessary to place the guns further apart than is advantageous.

Next, let us assume the point A 3 ft. from the face D E, as in fig. 2.

H K and L M will represent as before the interior sides of the embrasure.

Draw H N, L O, parallel to A B and A C, and describe the genouillère as before.

Fig. 2.



The angles at H and K are now rendered obtuse, and are protected from the effects of the enemy's fire by the masses D H and E L.

All the shot that can enter direct from the exterior must come from within the angle B A C, and consequently from within the limits of the lateral range of the gun.

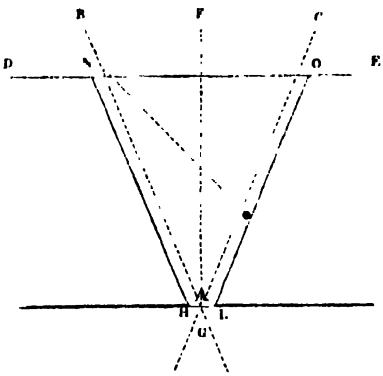
The protection from enfilade fire when the piece has recoiled will not in this case be quite so complete as before, but the interior opening (K M) is diminished, so that the guns can be placed at shorter intervals.

Supposing the point A to be placed further into the interior, the protection

from enfilade fire will be materially lessened, and the exterior opening will be necessarily enlarged.

If placed in the interior crest of the parapet, as in fig. 3, all protection from enfilade fire is lost; the angles at H and L again become acute, though the action of the shot will be more oblique on them than in the first case: the same objections, as regards the weakening the parapet, and the consequent distance apart of the guns, can be urged as before, and a very large exterior opening is presented for the entrance of many shot, which could not possibly have entered the embrasure in the former cases.

Fig. 3.



It is evident therefore that the distance of the point A (on which the gun traverses) from the exterior face of the escarp, should be a minimum, allowing a sufficient depth of resistance to protect the angles at the shoulder.

Adopting therefore our second figure as least objectionable, let us endeavour to accommodate it as much as possible to the conditions stated above.

The width of the opening at A will be determined by running the gun out at its extreme traversing limits.

All shot from the exterior whose direction is within the limits B A, C A, will enter into the interior of the embrasure without opposition.

Now as the gun only occupies a part of the interior opening, it will evidently be desirable to protect the men by blocking up the remaining part which is not required for the service of the gun.

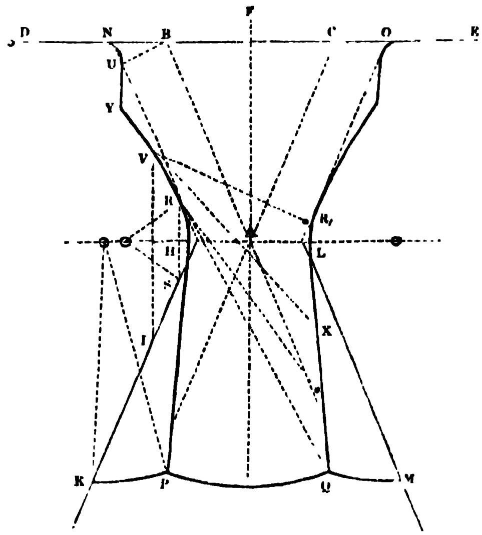
This may be effected by two blocks or mantlets of stone (H K P, L Q M, see fig. 4), faced with iron, and fitting the space not required at the time, capable of being moved at pleasure to accommodate the traverse of the gun. They may move on small iron shot placed in two circular grooves, so that

when the gun has recoiled, if the direction is to be materially altered, the mantlets can be moved accordingly.

The form of these must be so regulated that the gun may be able to fire in any direction between its extreme limits; *i. e.* the extreme right or left line of fire, where it is in the central position, as in Plate XXXII. fig. 5, must correspond with its extreme left or right line of fire when it is in the other positions.

The gun will then have a traverse of about 15° in each position.

Fig. 4.



In order that these two mantlets may close when brought together, the curves on which they move must be described from the point in the central line of the embrasure produced, in which the inner faces (P H, Q L) meet when produced.

Although from the form of the embrasure an exterior opening of only 4 feet is visible from the outside, it may still be of advantage to break up the straight faces (H N, L O) into such a form that grape and case, or even round shot, on striking them obliquely, may not ricochet into the interior, provided that the angles of the shoulder are not materially weakened by it.

Draw B U perpendicular to A B; this, being equal to half the width of the gun, will allow room for the shot when the gun is at its extreme left traverse.

In H U take the point R, so that R S perpendicular to H L = 1 foot.

Direct R V on the point Q, so that V T = 3 feet.

Through V draw Y V X, so that the angle U V Y = ∠R, V X.

Draw U Y so that the angle V U Y = 30°.

With radius T R = 1 foot, describe the curve R S.

Then no shot, after striking the side of the external part of the embrasure, can ricochet into the interior.

It having been proved that 30° is the extreme angle at which shot will ricochet on striking masonry,[1] it is evident that no shot can ricochet into the interior at P Q after striking the face V R; for the most oblique shot that can strike it will be in a direction within N R, which would, on ricocheting, strike L Q at an angle exceeding 30°. In the same manner the most oblique shot that can strike the next face V Y, being in the same direction, viz. within N R, it is stopped on ricocheting by the face L R. (As the ∠U V Y is 25°, nearly all the shot striking this face will be stopped by it without any danger of their ricocheting).

The ∠V U Y being made equal to 30°, all the shot striking the face U Y sufficiently obliquely to ricochet, will be thrown against the last face V Y, and thus effectually stopped from entering within the opening H L.

Note.—" On a shot striking masonry or brickwork, the angle of incidence will not be equal to the angle of reflection, as the hold which the shot takes must tend to stop it in some degree, and would therefore increase the angle of reflection."[2]

The other side of the exterior opening being completed in a similar manner, the faces of the embrasure are thereby removed from the effects of the explosion of the charge at the points where they are most liable to act upon them, though, where they are faced with stone, much injury arising from this cause is not to be feared.

As the muzzle of the gun when fired is within so short a distance of the outer face of the work, the smoke is not likely to be retained for any length of time, the greater part of it being projected clear of the embrasure the moment the gun is fired.

In order to facilitate the working of the gun when it is at its extreme right or left traverse, the interior faces of the embrasure may be formed as shown in

[1] At a velocity due to a charge ⅓rd the weight of the shot.

[2] This will compensate in some measure for the loss of velocity, which would probably increase the angle of ricochet.

to these two last described have been erected on the line of the Northern and Eastern branch of the Eastern Counties Railway.

Plate XXXVII. exhibits an arrangement which is applicable to a railway on a viaduct of arches, and such as is adopted on the London and Blackwall Railway, two of the arches being enclosed and roofed over. Fig. 1 is an upper plan; fig. 2 the lower plan; fig. 3 exterior elevation; and of fig. 4, one-half is sectional through the arch, and the other half sectional through the building. The building comprises a pay office and waiting hall, besides four closets in two sets. A flight of stairs projects on each side from the face line of the arches, and serves for the arrival and departure of the passengers, according to the direction of the train.

The remaining figures on Plate XXXVII. represent a single-floor station, having a booking office and general waiting-room, 32 feet by 17 feet 3 inches, a parcels office, 22 feet 9 inches by 13 feet 1½ inch, and a ladies' waiting-room, besides conveniences for both sexes. Fig. 5 is a front elevation of the building; fig. 6 a plan; fig. 7 an end elevation; fig. 8 a longitudinal section on the line A B on the plan; and fig. 9 a cross section through the booking office. This station is erected on the line of the Birmingham and Derby Junction Railway, now belonging to the 'Midlands' Company.

The terminus of a long line of railway comprises complete arrangements for carrying on a large passenger and goods traffic; and in its immediate vicinity it is necessary to provide means of repairing, and perhaps of constructing the locomotive engines, besides proper places for containing them, and arrangements for supplying the requisite fuel and water. The buildings may be arranged on the two sides of the space intended for the station, the goods warehouse or station adjoining, if convenient; but the locomotive engine-house should occupy a separate space, and be at some distance from the other buildings, to avoid, as far as possible, the annoyance of the noise, steam, and smell, which necessarily pervade the engine-house, and also the danger of communication in case of fire. The buildings will contain waiting-rooms for passengers, separating the first from the second and other classes, separate conveniences for each sex, booking offices, superintendent's office, store-rooms for lamps, oil, grease, &c., &c., rooms for clerks, porters, &c., and also suitable apartments for supplying refreshments. Around the two sides, or two sides and end, as the case may be, of the interior space enclosed by the buildings, a platform, about 10 or 12 feet wide, is constructed, covered with planking, stone

flags, or asphalte, and about 2 feet 6 inches above the level of the rails, by which facility is given for entering and leaving the carriages, and also for loading the railway trucks with carriages, horses, cattle, sheep, goods, &c. The whole of this interior space is roofed over, and lighted by sky-lights or louvre-lights in the roof. Several examples of iron roofing applicable to stations are illustrated and described in the previous volumes of the Professional Papers.

On approaching the station, the two lines of rails diverge from each other, so as to bring them close against the platforms, one of which serves as the departure platform, having booking offices, &c., contiguous to it, and the other as the arrival platform, in the immediate vicinity of which the refreshment rooms are suitably situated. The space between the two lines of rails must be wide enough for three or more spare lines of rails, to hold carriages of all classes, horse boxes, carriage trucks, &c. Access from the main lines to these spare lines is obtained by one, two, or more rows of turn-plates, one of which should be placed across each of the extreme ends of the station, and another intermediate, so that first, second, or third class carriages, may be conveniently introduced at any part of the train. Switches may also be laid connecting these spare lines with the main lines, but they should be of such a kind that the tongues may be wholly removed, except when in use, otherwise the arriving trains will run against the points. The roofing is supported by light iron girders, resting upon iron columns, fixed in rows between the spare lines of rails. The goods warehouses, if adjoining the station, should be kept back from the line formed by the other buildings, so as to allow one or more spare lines between the warehouse and the main line. If this cannot be done, the turn-plates must be fixed upon the main line, which is found objectionable, as they are thus exposed to a constant and most destructive kind of wear.

Plate XXXVIII. represents a goods station of considerable extent, having five places for trucks to be run in and out, and being connected with one line of rails and two sidings by means of seventeen turn-plates. A raised platform, 26 feet in width, extends along the centre of the building, and throughout its entire length, being divided by cross partitions into five spaces corresponding with the five loading-places from the turn-plates. In each of these spaces a small crane is erected; and bracket cranes are also fixed outside the building over the doorways and above the upper floor. On the other side of the platform a roadway is made through the building, for the admission of road-carts

and waggons to deliver and receive their loads. Figs. 1 and 2 are side elevations of the building; fig. 3 is a plan; fig. 4 a cross section; and fig. 5 an end elevation.

The most convenient form in which buildings for standing engines are constructed is polygonal. Plate XXXIX. represents a complete arrangement for one having sixteen engine-pits, in each of which two engines may stand, thus affording standing room for thirty-two engines. All the pits are radial from the common centre of one turn-plate, and thus any of the engines may be by one movement of the turn-plate transferred from the pit over which it happens to be standing to either one of the two pits which communicate with the railway. The two entrances from the railway are covered in, forming buildings about 50 feet long and 27 feet wide, and having cast iron tanks above, supported upon girders. These tanks serve as reservoirs for water, to be supplied by the cranes into the tenders outside the building. Fig. 1 is an external elevation; fig. 2 a plan, one-quarter of which is shown above the brick foundations, another quarter over the pits, and showing the position of the columns which support the roof; a third quarter of the plan shows the arrangement of the rafters, and the other the top plan of the roof; fig. 3 is a section of the house, taken on the line A A on the plan.

Plate XL. represents a house adapted for the repair as well as the standing of locomotive engines. Fig. 1 is a longitudinal elevation, and fig. 2 a plan of the building; fig. 3 is a longitudinal section on the line A A on the plan; fig. 4 a half end elevation; fig. 5 a cross section on the line C C on the plan; fig. 6 a cross section on the line B B on the plan; figs. 7, 8, and 9, are details of the cap of the chimney, the stack of which is shown, in connection with the elevation (fig. 1), by dotted lines which extend across the plan. This building contains two long pits; also one central pit for the standing of engines to be repaired; a repairing shop, smiths' shop, engine-room, superintendent's office, store, &c. The doors are suspended by rollers, which run on rails fixed over the openings.

The provision of the required quantity of water for supplying the tenders constitutes one of the most important objects to be secured at terminal stations. Along the line, watering stations will suffice at intervals of about 20 miles. In some cases, contiguity to a river, or other natural source of the required supply, will make the arrangements simple, but, if much pumping be necessary, a small steam engine will be found an economical adjunct to the watering

arrangements. The four Plates XLI. to XLIV. represent the details of a complete watering apparatus, including pumps, engine, boilers, &c., as used on the North Midland Railway, and also two varieties of water-cranes. Plate XLI. shows a general section and plan of the building and well, and the arrangement of the pumps, engine, tank, &c., &c.; Plate XLII. exhibits the pumping apparatus and valve in detail; Plate XLIII. contains details of the engine and boilers; and Plate XLIV. shows a balance water-crane and a bracket water-crane, both kinds being extensively used.

On Plate XLI., fig. 1 is a vertical section of the building and well, and elevation of the machinery; and fig. 2 is a plan of the building, well, and machinery. *a* is the well; *b b* the rising mains, supported by cast iron girders, *c c*, resting in recesses in the well; *d* the double-throw pumping gear, fixed on cast iron frames carried upon oak girders, *e e*, resting across the brick-work of the well; *ff* are the pump-rods; *g g* the cranks; *h h* the connecting branches, and *i* the tank supply-pipe; *j* the tank, formed of cast iron plates with flanges, through which bolts are screwed, and iron cement inserted between the flanges. The tank is supported upon cast iron girders, *k k*, which span the building, and rest upon the walls. The tank is strengthened with wrought iron stay-rods, *l l*, fixed by bolts and eyes across the angles: *m* is a valve for admitting the water to descend the pipe *q*, into the lower end of which the pipe *r* is fixed, which is connected with the water-crane adjoining the rails. The valve, *m*, is opened by means of the chain, *p*, lever, *n*, and rod, *s*, and closed by the counterweight, *o*, when the chain is released; *t* is the waste-pipe. The same letters refer to the same parts shown in figs. 1 and 2, Plate XLII. Figs. 4 to 12 inclusive, exhibit details of the valves, and fig. 13 is a sectional plan, taken on the dotted line *z z*, of the rising main, *b*, and connecting-pipe, *h*. Reverting to Plate XLI., *u* is the pump-shaft, *v* the fly-wheel, *w* the crank, *x* the connecting-rod, *y* the steam engine, *z* the steam pipe, and *b o*, *b o* the boilers.

Plate XLIII. represents the engine and boilers in detail. The engine is of four horses' power, and of the high-pressure kind. Fig. 1 is a side elevation of the engine, and fig. 2 a plan; fig. 3 shows the front end, and fig. 4 the hinder end; fig. 5 is a longitudinal section of the cylinder, and fig. 6 a cross section through the steam chamber; fig. 7 is a longitudinal section of one of the boilers; fig. 8 a front elevation; fig. 9 a plan; and fig. 10 shows cross sections, one through the fire-bars and safety-valve, and the other in front of it.

Plates XLV. and XLVI. contain elevation, sections, and details, of a hoisting apparatus employed on the London and Blackwall Railway, chiefly for the purpose of loading the railway trucks with sugar hogsheads. The hoisting station is situated near to the West India Dock warehouses, whence the hogsheads are brought in low trucks, each of which holds two hogsheads. Three of these loaded trucks (from which the horse-shafts are readily removed) are then hoisted upon one of the railway trucks, and thus are transferred to the London end of the line, where they are discharged by means of another hoisting machine. The station shown on Plate XLV. is constructed upon eight cast iron columns, marked *a a*, built upon brick foundations, bedded upon concrete: the columns are secured by strong iron holding-down bolts, which pass through iron plates built in the brick foundations. Above the columns a cast iron entablature, *b b*, is fixed, and supports eight girders, marked *c c*, upon the inner lower flanges of which wrought iron rails, *d d*, are bolted, forming six roads for the traversing cranes, (of which one, marked *e*, is shown.) The roofing is supported upon cast iron standards, *i i*, to which are bolted iron shoes, *j j*, for the feet of the principals: *h* is the railway truck, *g g* are the horse trucks, and *f f* are the hogsheads. Fig. 1, Plate XLV., is an elevation of one-half of the building, and fig. 2 a section of the other half, both being longitudinal with the railway; fig. 3 is a half section across the line. On Plate XLVI., fig. 1 is a side elevation, and fig. 2 a front elevation, of the traversing crane. *a a* are side frames, which were intended to be made of wrought plate iron, but were cast with ribs; *b b* are the axes of the running wheels; and *c* the shaft of the drum, *j*, and the oblique toothed wheel, *i*. The load is raised with a windlass, *g*, having a worm or endless screw, *h*, which works into the wheel, *i*. The crane is made to traverse across the station with a hand-crank, *k*, on the shaft of which is a pinion, *l*, that works into a geared wheel, *m*, on one of the running wheel-shafts, *b*. *d d* are the wheels; *e e* the girders; and *f f* the wrought iron rails, bolted on their lower flanges. The men working the crane stand upon a platform, *q*, supported by stay-rods, *n*, *o*, and *p*, secured to the side frames.

Plate XLVI. also contains a few details of sheaves, as applicable for guiding the ropes used on inclines, and with stationary power. Figs. 3, 4, and 5, show the cast iron sheaves first applied on the London and Blackwall Railway: fig. 3 shows an elevation of the sheave, and section of the bearing-box or frame, *b b*, embedded in the ballasting; fig. 4 is a half plan, sectional through a

sheave having an oblique rim, *c*, as adopted for guiding the rope round curves, the higher side being intended to prevent the rope taking the direction of a straight line, as it has a tendency to do, when strained: fig. 5 is a similar half plan, sectional through a sheave, *d*, intended for the straight parts of the railway. The axis, *g*, of the sheave turns in bearings, *e e*, having receptacles for grease with lids, *f f*. Figs. 6, 7, and 8, represent a kind of wooden sheave which has been extensively substituted for the iron ones already described. The sheave is made in two halves, *a a*, secured together by wrought iron rings, *b b*, sunk in the face of the sheave and bolts, *e e*, the heads and nuts of which are also sunk: two iron plates, *c c*, are let into the sheave, and have round holes and key-ways for the axis of the sheave. Figs. 9 to 13 inclusive show two varieties of sheave adopted round curves on the Euston extension of the London and Birmingham Railway. Figs. 9 and 10 are elevation and plan of two small curved iron rollers, the meeting surfaces of which are bevelled: they are supported by a wrought iron standard, having two branches or axes, upon which the rollers are secured by screwed nuts: the surfaces, *b* and *c*, of these rollers form together a continuous curved surface, over which the rope passes, and which, whether the rope presses laterally or vertically, yet revolves, and thus avoids the friction which arises from the rubbing of the rope against the sides of the groove of a sheave which revolves on a horizontal axis only. Figs. 11, 12, and 13, show another contrivance applied on curves, which consists of a common sheave working in a box, placed obliquely, and having attached to it a fixed iron guard or frame, *c c c c*, intended to bear the rope if it escapes from the groove of the sheave: *a* is the sheave, and *b* the box. Figs. 12 and 13 show a dovetailed recess in the sides of the box, within which blocks of hard wood (lignum vitæ, teak, or elm) are fitted. The ends of the axis bear in these blocks, and are greased through a vertical hole bored in the block.

In a former Section reference was made to a substitute for turn-plates, sometimes adopted, in the shape of a traversing platform, made to cross the railway so as to present either of two lines of rails fixed upon it in connection with the fixed rails. Such a contrivance, as applied on the Great Western Railway, at Paddington, is shown in detail on Plates XLVII. and XLVIII., on which the same letters refer to the same parts.

On Plate XLVII., fig. 1 is a plan of the platform, from half of which the top planking is shown removed, for the purpose of exposing the framing, &c., beneath: fig. 2 is a half cross section, and fig. 3 a half cross elevation; figs. 4

and 5 are half sections taken longitudinally with the railway: *a a a a* are the two sets of rails on the platform, and *b b b b* the corresponding fixed rails. The framing of the platform consists of four parallel joists, *d d d d,* fixed in two pairs for the bearings of the running wheels. Upon these joists four others, *c c c c,* are bolted, corresponding with the positions of the rails, and supporting them. Three pairs of longitudinal braces, *f f,* and two diagonal braces, *e e,* are fixed between the main timbers, *c c c c,* and notched down upon the joists, *d d d d.* The platform traverses upon four iron wheels, *i i i i,* the bearings, *l l l l,* of which are fixed to the joists, *d d d d.* These wheels run upon two rails, *h h,* laid beneath, and supported upon timbers, marked *g g.* The motion is guided by four horizontal rollers, *r r r r,* which are attached to the framing of the platform, and work against fixed iron guide-rails, as shown in fig. 10, Plate XLVIII. *k k* are two timbers, notched down upon the ends of the rail-joists, *c c c c.* The platform is covered with planking, and made partly removeable, to give access to the wheels and the centre moving apparatus. The running wheels stand partly above the planking, and are protected by sheet iron caps, *j j j j.* The movement of the platform is effected by means of an endless chain, *o o,* connected to the framing of the platform by a fixed hook, *p,* fig. 5, Plate XLVII. The chain passes over two grooved pulleys, *m* and *n,* the axes of which are fixed beneath the platform, and the grooves of which have indentations to secure the adhesion of the chain. The chain is guided upon small rollers, *a d, a d,* shown at figs. 3, 8, and 9, Plate XLVIII. The motion of the pulleys, *m, n,* is effected by the gearing shown generally at *q,* fig. 1, Plate XLVII., and in detail at figs. 1, 2, and 3, Plate XLVIII. Bolted to the pulley, *n,* is a large toothed wheel, *w,* which is worked by a pinion, *x,* on the upper end of the shaft of which is a bevelled wheel, *y,* to which motion is given by the other bevelled wheel, *z,* moved by the winches, *a b, a b.* The gearing is supported in a cast iron frame, *a a,* the bed-plate of which, *a c,* embraces the curb adjoining the platform.

On Plate XLVIII., figs. 1 and 2 are front and side elevations of the gearing, fig. 1 showing the pulley, *n,* and toothed wheel, *w,* in section: fig. 3 is a plan of the upper and lower gearing; figs. 4 and 5 are elevation and section of one of the running wheels, *i*; figs. 6 and 7 are elevations and section of the pulley, *m*; figs. 8 and 9 are elevation and section of one of the chain pulleys, *a d*; and figs. 10 and 11 are elevation and section of one of the guide-rollers, *r.* In fig. 1, Plate XLVII., a latch, *s,* is shown, by which the platform is secured in

its usual position. The latch falls into a notch, *t*, on a fixed plate, turns upon centres at *v*, *v*, and is limited in its movement by the strap, *u*.

Plate XLIX. represents various views of a first class railway carriage. Fig. 1 is a side elevation; fig. 2 is a plan of the under carriage; fig. 3 an end elevation; and fig. 4 a cross section through the body and under carriage. These carriages consist of two main portions, the manufacture of each of which is comparatively distinct from that of the other. These portions are,—the 'under carriage' or 'frame,' including wheels, springs, buffers, brakes, &c.; and the 'body,' which comprehends all above the framing. The one is made with a view chiefly to strength, and requires smiths, joiners, &c.; and the other is adapted to afford comfort and convenience to the passengers, requiring building, stuffing, glazing, painting, &c., &c. The carriage shown on the Plate has three compartments, and holds eighteen passengers. It stands on four wheels, and has a guard's seat at each end. A continuous lower footboard, *a a*, is fixed along each side of the body, and separate steps, *b b b*, at the doors. The buffer-rods, *c c*, pass through the end bars, *d d*, of the framing, and also through the cross-ties, *e e*, and are formed at the ends, *g g*, with grooves or paths, in which the rollers attached to the ends of the buffer-springs, *h h*, move when a pressure on the buffers tends to straighten, and thus elongate, the springs. The springs are strapped at the middle, *i i*, to the ends of the draw-bars, *j j*, *k k* being the hooks by which the carriages are connected together. The springs are thus made available in diminishing the effect of sudden jerks in the draught. *f f* are the side sole-bars, and *l l* the diagonal braces; *m m* are the bearing-springs, and *n n* their carriages, the distances of which may be regulated by screwed bolts, marked *o o*, and of which details are given in a subsequent Plate; *p p* are the axle-guards, and *q q* the axle-boxes. Besides the coupling which connects the carriages by the draw-hooks, *k k*, two reserve side chains, *s s*, are provided with hooks at their extremities: *r* is the wrought iron rod connecting the axle-boxes.

The principal dimensions are as follow: length of frame, 18 feet; width of ditto, 7 feet 6 inches; diameter of wheels, 3 feet; width of ditto, 4½ inches; height from level of rails to under surface of frame (unloaded), 3 feet 10 inches; extreme height of body from rail level (unloaded), 10 feet 5 inches; extreme width of body, 8 feet. The scantlings of the principal parts are as follow: side soles, *f f*, 10 by 4 inches; end soles, *d d*, 10 by 4 inches; cross-ties, *e e*, 7½ by 3 inches; diagonal braces, *l l*, 4½ by 1½ inches; bearing-springs, *m m*,

each thirteen plates, 3 inches by $\frac{5}{16}$ths of an inch; buffer-springs, *h h*, ten plates, 3 inches by $\frac{5}{16}$ths of an inch; buffer-rods, *c c*, $2\frac{1}{4}$ inches diameter, reduced to $1\frac{3}{4}$ inch; draw-bars, *j j*, 2 inches diameter.

Plate L. Figs. 1 and 2 show side elevation and plan of second class carriage, the framing of which is precisely similar to that of the first class carriage just described. The body of this second class, however, consists of four compartments, of which three are double-seated, and one single-seated. Four passengers filling one seat, this carriage is adapted to hold twenty-eight persons. Figs. 3, 4, and 5, show an open third class carriage; fig. 3 is a side elevation; fig. 4 a half plan; and fig. 5 an end elevation. The seats are so arranged that the whole space of the carriage is accessible by a single door. Two doors are however provided, one opposite to the other, and situated in the middle of the sides of the carriage. This carriage is adapted to hold about thirty-two persons. The carriages which have lately been established on most of the English railways under an order in Parliament, and hence called 'Parliamentary' or 'Government' carriages, closely resemble the one here shown, in the position of the doors and arrangement of the seats, but differ from it (in accordance with the Parliamentary order) in being wholly enclosed; the sides being continued upwards, and roofed over, and having two or more small glazed openings on each side.

Plate LI. contains various details which are common to most of the best made first and second class railway carriages. Figs. 1 and 2 are intended to show plan and longitudinal section of an under carriage frame, with the springs, &c., complete, and to a larger scale than is practicable in showing the entire carriages. In these figures, *a a* are the side sole-bars, *b b* the end sole-bars, *c c* the cross-ties, *d d* the diagonal braces. The side and end sole-bars and braces are secured together by iron knees, *e e*, firmly bolted; the side sole-bars and cross-ties are secured together by iron knees, *n n*, which also are made to serve as guides for the buffer-rods, *f f*, to work in. The ends of the rods are formed with grooves at *g g*, for the rollers at the ends of the buffer-springs, *h h*, to work in. *i i* are the draw-bars, the ends of which have projecting studs that press against the small springs, *j j*, when the draw-bars are in a state of tension. The ends of the small springs, *j j*, are connected to two pairs of rods, *k k*, and the whole of the spring apparatus is secured between two pairs of parallel plates, *l* and *m*. Figs. 3 and 4 show a front and side view of the 'axle-guard,' which is cut from an iron plate, and about $\frac{1}{2}$ or $\frac{5}{8}$ths of an inch in thickness.

The axle-guards are the only means of connecting the carriage framing to the wheels. The wheels are firmly keyed on to the axles, and therefore the axles revolve with the wheels. The axle is prolonged at each end beyond the wheels, forming its journals. A separate metal box adapted to hold grease, and a gun-metal bearing, and made in two parts to admit the journal of the axle, and hence called the 'axle-box,' is fitted at each end of the axle. As the height of the carriage and framing varies according to the load and pressure on the springs, while the height of the axle-box of course remains the same, it is necessary that their connection should admit of this variety of altitude, and of distance between the framing and axle-box. This adjustment is provided by bolting the axle-guards to the framing (on the inside of the side sole-bars), and making grooves in the sides of the axle-box, within which the prongs of the guard may move vertically only. These grooves are shown at *a a*, fig. 8; figs. 5, 6, 7, and 8, being views of one of the axle-boxes; fig. 5 a longitudinal section, showing the axle, and the position of the wheel upon it, the journal, and the gun-metal bearing. *b* is the aperture through which the grease is admitted to the journal; *c c* are small tongues formed on the gun-metal bearings, fitting into corresponding notches in the axle-box, and thus preventing the bearing from shifting on the journal; *s s* are small straps of iron, or spring-ties, by which the springs are secured. The upper and lower parts of the axle-box are connected by means of two strong screwed bolts and nuts, *d d*. The space for grease is usually covered by a lid of sheet iron, turning on a hinge joint, but omitted in the figures to avoid complexity. Fig. 6 is a side elevation of the axle-box, showing a portion of the wheel and axle; fig. 7 is a half front view and half cross section of the axle-box, showing the gun-metal bearing and position of bolts, *d d*; and fig. 8 is a half top plan and half underneath plan of the box.

Fig. 9 shows one of the couplings, known as 'Booth's coupling,' by which the carriages in a train are almost universally connected together. *a a* is a screw, one-half of which is cut with a right, and the other with a left-handed thread, so that one movement of the screw shall either increase or diminish the distance between the tapped sockets, *e e*. These sockets are connected by pins to the links, *f f*, which are put over the hooks, *k k*, of the draw-bars of the carriages. For convenience in turning the screw, *a a*, it is attached at the centre, *b*, by a pin to a lever or stalk, *c*, the weight, *d*, at the end of which tends to keep the screw stationary, and thus prevent any accidental movement of it.

In order to show the coupling complete in one view, the weight, *d*, and stalk, *c*, are shown as if lying horizontally, whereas they naturally assume a vertical position when the coupling is in use.

The braking apparatus, as usually applied to railway carriage wheels, consists of two or four blocks of wood fitted to the periphery of the wheel, and about 15 inches long, 5 inches wide, and 3 inches thick. To these strips of iron are attached at the back, and these strips are slung by iron pins from the sole-bars of the framing. The blocks are so connected by iron rods that a movement which is horizontal, or nearly so, is required in order to force them against the wheels. The apparatus by which this motion is commonly obtained, at command of the guard seated above the carriage, is shown by figs. 10 to 14 inclusive, on Plate LI. *a b* are a lever and handle, conveniently situated beside the guard's seat, and keyed to a vertical iron rod, *c*, which turns within an eye or bearing, *d*, fixed by means of two bolts to the upper part of the carriage body. The lower end of this rod is cut with a square-threaded screw, *e*, and its lower point turns in a tapped socket, *h*, which is secured at *i* in the end sole-bar, *j*, of the carriage framing. Another tapped socket, *g*, is also fitted upon this screw, and connected by a pin with two side slings, *f f*, the lower ends of which are pinned to a double-armed or bell-crank lever, *k*, *l*, which is keyed to a shaft, *n*, that turns in an eye, *m*, bolted to the carriage framing. By turning the handle, *b*, so as to raise the rod, *c*, the end, *p*, of this lever will be evidently drawn forwards in an arc, whereof *n* is the centre; and by extending the shaft, *n*, across the framing, two sets of brake-rods may be simultaneously acted upon, so as, if required, to work four brakes at once.

Figs. 15 and 16, Plate LI., show a detail of the carriages for the ends of the bearing-springs (as shown on Plates XLIX. and L.), which are capable of adjustment, according to the length of the springs. *a* represents the side sole-bar of the carriage framing; *s* the end of the spring; and *c* the iron bracket or carriage, to which the spring is connected by the sling, *d*, which consists of a steel link enclosed in one of leather, and embracing small rollers on the end of the spring and of the carriage. The bearing-plate, *e e*, has two slots, *f f*, working upon the bolts, *g g*, fixed in the sole-bar: *h* is another bolt firmly fixed in the sole-bar, and *i* is a screwed bolt which passes through eyes formed on the bolt, *h*, and on the end of the bearing-plate, *e*. By screwing up the nut upon this bolt, *i*, the bearing-plate, *e*, will be evidently drawn further away from the spring, and *vice versâ*.

Plate LII. shows a railway waggon adapted to carry a large quantity of heavy goods. Fig. 1 is a side elevation; fig. 2 a plan of the carriage framing, one half of which is shown above the upper frame; fig. 3 an end elevation; and fig. 4 a half top plan. *a a* are the side sole-bars; *b b* the end sole-bars; *c c* the cross ties, and *d d* the diagonal braces: *e e* are the buffer-rods, and *f f* the rollers on the ends of the buffer-springs, *g g*: *h h* are the draw-bars; and *i i* the hooks for the couplings. The draw-bars are connected at *j j* to the buffer-springs. *k k* show the framing of the body, and *l l*, *m m*, that of the doors, of which there are two at each end of the waggon: *n* and *o* are the iron fastenings to the doors. The doors are continued upwards at *p p*, for additional security to the load. *q q* are the axle-guards, *r r* the axle-boxes, and *s* the connecting-rod between them.

Plate LIII. represents a ballast waggon, the height of which may be increased at pleasure by the sides and ends, *a a*, secured by the posts, *b b*, in the staples, *c c*. This waggon is without buffers, and the draw-bars, *d d*, are provided with very simple springs at *e e*. Fig. 1 is a side elevation; fig. 2 a plan; fig. 3 an end elevation; and fig. 4 a half top plan of the waggon.

On Plate LIV., figs. 1 to 9 inclusive show the details of a very effective brake, applicable to ballast and other waggons, where the action can be had direct by means of a lever. *a* is the lever terminating in a handle, and working within a slot formed on a plate, *b*, having a series of holes, in which a pin is placed, in order to retain the handle in any desired position. When out of use, the handle is kept in its highest position by the spring-stud, *v*, shown at figs. 8 and 9. The other end of the lever is connected at *c*, with a bell-crank lever, having two arms, *s* and *e*. The pin to which the lever, *a*, and the bell-crank lever, are keyed at *c*, turns in two iron plates, *d d*, bolted to the side sole-bar, *t*, of the waggon. The two ends, *s* and *e*, of the bell-crank lever, are pinned to the brake-rods, *f f* and *r p*, the other ends of which are attached by bolts to the iron plates or shoes, *h* and *n*, bolted to the brake-blocks, *i* and *o*, and suspended by slings, *k* and *m*, at *j* and *l*, from the side sole-bars of the carriage. The brake-rods are each made in two pieces, the approaching ends of which are tapped reversely, so that by turning the tapped nuts, *g* and *q*, which connect them, their length may be from time to time increased, to make up for the deficiency occasioned by the wear of the wooden blocks, *i* and *o*, against the wheels. Fig. 1 is a partial view of the waggon; fig. 2 a cross section of the side sole-bar, *t*, with the bell-crank lever and pin, *c*, in connection; fig. 3 is a

separate side view of the bell-crank lever; and fig. 4 is a front view of one of the pins, *s*, showing the separate collar secured to it, after attaching the end of the brake-rod. Fig. 5 is a separate view of the brake-rod, *f f*, showing the block, *i*, and shoe, *h*, in section. Figs. 6 and 7 are separate side and front views of one of the shoes, *n*, with its sling, *m*, and pin, *u*, by which it is secured to the side sole-bar, *t*; and figs. 8 and 9 are side and front views of the handle-plate, *b*, with its spring-stud, &c. Figs. 10, 11, and 12, show a simpler and less effective form of brake, applicable to a similar class of railway waggons, and which acts only on one wheel. The same letters in these figures refer to similar parts to those described of fig. 1, &c.

Figs. 13 and 14 represent the grip or clutch attached to the two ends of the carriages, &c., used on the London and Blackwall Railway. Fig. 13 is a front view; and fig. 14 a section taken on the line A A on fig. 13. *a* is the end sole-bar, which extends beyond the body of the carriage, and is planked over, the guard standing on this projection in order to have immediate command over the grip and brakes: *b b* are two tongues or forks, not placed in the same plane, but fixed one behind the other; and *c* is a moveable tongue or hook, working between them, and which is thrown back in order to admit the rope between the forks, *b b*, then forcibly pressed upward, so as to secure a firm grip of the rope, and again thrown back, on approaching the stopping-place, so as to release the rope. The moveable tongue, *c*, terminates upwards in a lever or handle, *d*, having a centre at *e*, on the radial lever, *g*, which turns on a fixed centre at *f*. The lever, *g*, has also a pinion on the end of a small lever, *j*, and a pall, *l*, on the end of another lever, *k*, attached to it. This pinion and pall work on the two edges of a fixed curved standard, *i*, one of which is formed with teeth, and the other with a ratchet. When the rope is embraced between the tongues, *b b* and *c*, the lever, *g*, is forced upwards, aided by pressing the handle, *j*, downwards; and when the required force is attained, the pall, *l*, is dropped into the nearest tooth of the ratchet. In order to release the rope it is only necessary to remove the pall, and press the lever, *d*, towards the standard, *i*. The levers, *d* and *j*, are kept in their proper planes by the ties which extend from *f* to *h*.

Figs. 15, 16, and 17, show a contrivance affixed to the ends of railway trucks intended to carry road carriages, for the purpose of receiving the wheels of such carriages. It consists of a metal plate, *b*, turning on centres at *c c*, and supported by a bracket, *f*, bolted at *g* to the end sole-bar: leading from the

plate *b* is an inclined plate, *a*, and both of these having raised edges, the wheels are with certainty conducted to the space intended for them, between ribs of wood bolted to the flooring of the truck. The dotted lines at *d* show the position of the plate or flap, *b*, when not in use.

Many contrivances and combinations have been attempted in the manufacture of wheels for railway carriages. In the early period of railway history, wheels made wholly of cast iron were tried, but found quite unequal to the wear occasioned by high velocities, and the concussions to which they were exposed over new lines, &c. Hence combinations of cast and malleable iron were tried, and, fashioned in a variety of shapes, these materials have ever since been most widely adopted. The boxes or naves are cast, and the arms or spokes, and rim or tire, are of malleable iron. In the ordinary forms the mode of manufacture is this:—the arms, being rolled and properly formed, are arranged in the positions they are intended to occupy in the wheel around a box or mould for the nave, and into which mould cast iron is introduced in a melted state. The attaching of the tire is another operation: the iron, being rolled to the proper section, and cut to the proper length, is next placed in a furnace, and then bent in a mould to the intended circular shape, after which it is shrunk on upon the arms and riveted to them. The finishing operation is the turning of the surface of the tire.

A machine for bending and setting the tires of railway carriage wheels was described in a paper by Mr. J. Woods, read before the Institution of Civil Engineers, in the session of 1841. The abstract of this description may be quoted from the 'Civil Engineer's Journal,'[1] as follows: "The usual mode of bending tire-bars was by means of swages and hammers round a fixed mandril: after being welded, they were stretched on a cast iron block, formed of two semicircular pieces hinged at one point, and wedged apart at the opposite side: the hoops, being heated, were placed on this block, and by repeated blows driven into close contact with the mould. Much difficulty was experienced in thus making up tires for large railway wheels, and the present machine was constructed for facilitating the process. One end of the tire-bar, when heated, is wedged into contact with one of four segments of a circle, of the required diameter, upon a cast iron table, which is caused to revolve slowly; the pressure of a guide-wheel at one side forces the tire-bar to warp round the segments,

[1] Vol. iv. p. 318.

and to form the circular hoop required; its ends, having been previously scarfed, are then welded together. The tire is again thoroughly heated, and placed around the four segments, which slide radially on the table, and are then simultaneously forced outwards by a motion of the centre shaft. The tire, being slightly chilled, and assisted by the swage and hammer, soon adapts itself to the segments, and forms a circular hoop instead of two semicircles irregularly joined at their points of contact, as by the old system: it is then ready for being chucked on the lathe, and bored out before shrinking on the wheel. It is apparent that a machine of this description becomes applicable to tires of any diameter, by having three or four sizes of segments adapted to the table. It is found to diminish the manual labour, and to prepare the tire more accurately than by the usual process."

On Plate LV. six varieties of railway wheels are shown. Fig. 1 is an elevation, side view, and section of a wheel, of which the nave or box only is of cast iron: the tire is rolled, and the spokes are formed of iron plate, 4 inches by ½ inch: each spoke consists of a pair of these plates, which meet at the tire, but diverge in curved lines towards the nave, and are by this arrangement intended to afford some elasticity. The plates forming the spokes are continued within the inner circumference of the tire, and secured by screwed bolts and nuts, the heads of the bolts being countersunk on the tire, and turned to lie perfectly flush with it. Fig. 2 shows similar views of another wheel, consisting of one member more than that just described, viz., a separate inner band or tire having a tongue or rib rolled on it. The spokes are formed of rolled iron, of a section resembling the letter T, and are curved so as to present arched surfaces towards the tire. Each adjoining pair of spokes meet in approaching the nave, into which they are fixed in the process of casting it. The arched surfaces of the spokes are formed with grooves, corresponding with the tongue on the inner tire; and both tires and the spokes are secured together by bolts, of which the heads are countersunk and turned off, and the inner ends are riveted through the crown of the arches formed by the spokes. Fig. 3 shows elevation, side view, and section of a wheel having cast iron nave and arms and rolled tire. The arms are of the H section, and cast together with an inner tire, and the two tires are secured together with wrought iron bolts, countersunk on the head, and turned with the tire. Fig. 4 exhibits a wheel, of which the arms are formed of iron plates similar to those shown on fig. 1; but in this wheel they are arranged so that the curvature or bow is transverse to the plane of the

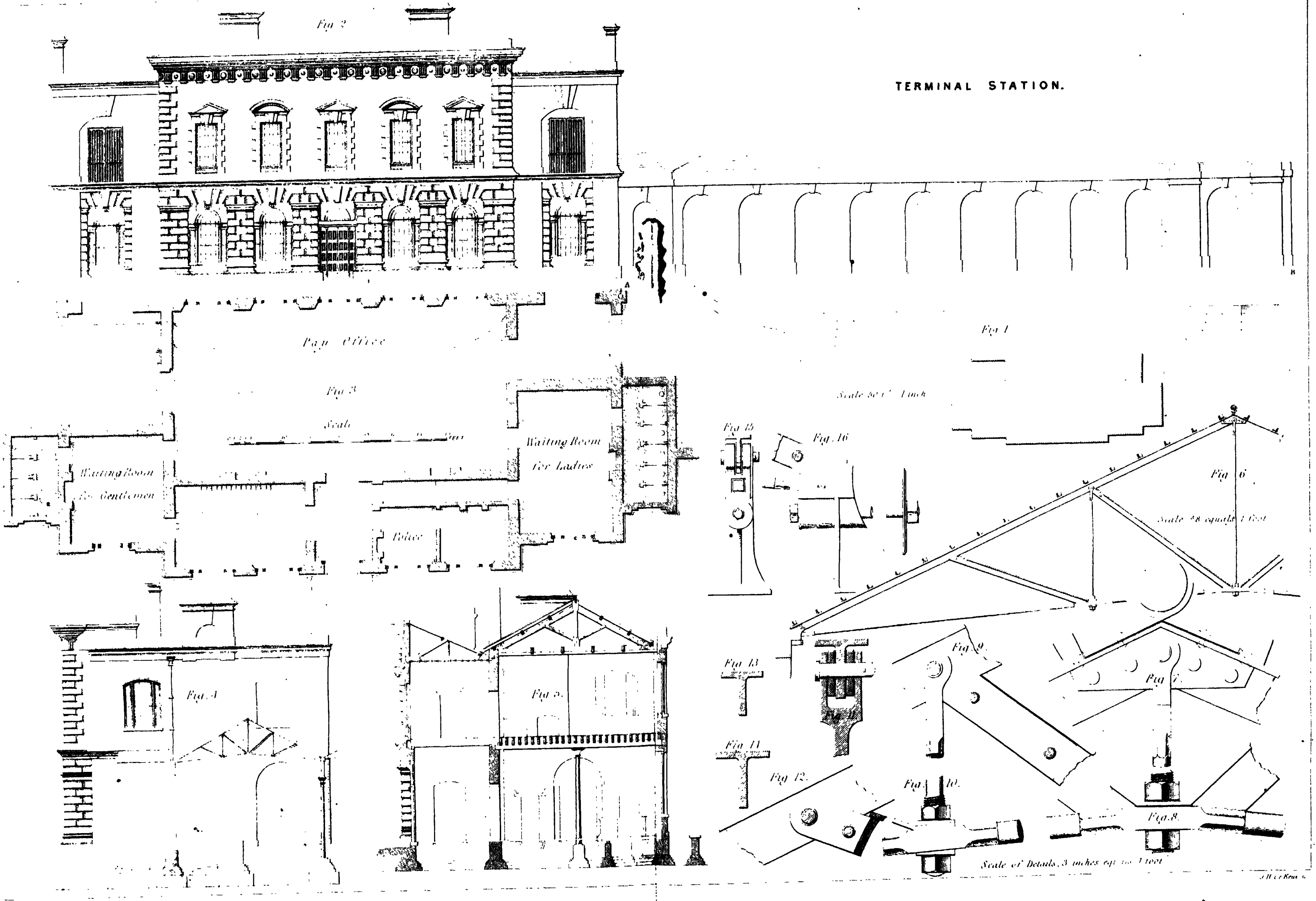
wheel, instead of being parallel to it. The meeting ends of each pair of plates forming the spokes are received between two tongues rolled on the inner circumference of the tire. In the wheels yet described metal only is employed, but in those shown in figs. 5 and 6 a portion of wood is introduced, whereby the quality of elasticity, so desirable in railway wheels, is sought to be obtained. In the wheel shown in fig. 5 the spokes are of wood, and are received in sockets formed in the cast iron nave, and at the outer ends mortised into an inner tire of wood, which is made in segments, and bolted to the rolled iron outer tire. In fig. 6, the bearing surface of the tire is formed of wood, which is fitted in small segments into a groove formed on the tire. The inventor of this wheel, Mr. Dircks, has thus described it.—"The construction of this wheel may be understood by imagining a spoked wheel with a deep channelled tire. The wheel may be made either of cast or wrought iron, it having been ascertained that tire-bars can be rolled to the required pattern. In this channelled tire are inserted blocks of African oak, measuring about four inches by three and a half inches, solidified by filling the pores with unctuous preparations; thereby counteracting the effects of wet by capillary attraction, to which by this means it becomes impervious, and at the same time is not liable to unequal contraction and expansion. The blocks of wood are cut to the requisite form to fit very exactly into the external circular channel of the wheel, with the grain placed vertically throughout, forming a complete facing of wood." There are about from twenty-eight to thirty of these blocks round each wheel, where they are retained in the required position by means of the bolts, as shown in the engraving.

G. D. D.

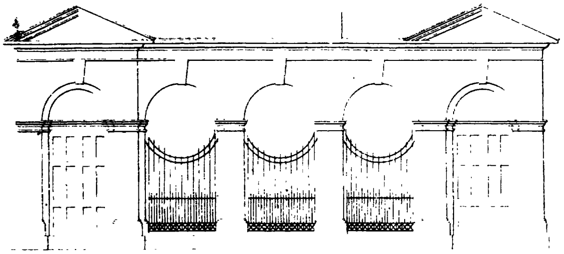
END OF VOL. IX.

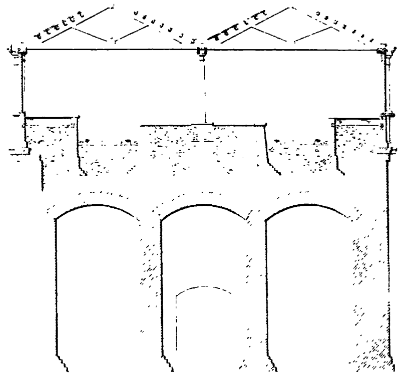
PRINTED BY W. HUGHES, KING'S HEAD COURT, GOUGH SQUARE.

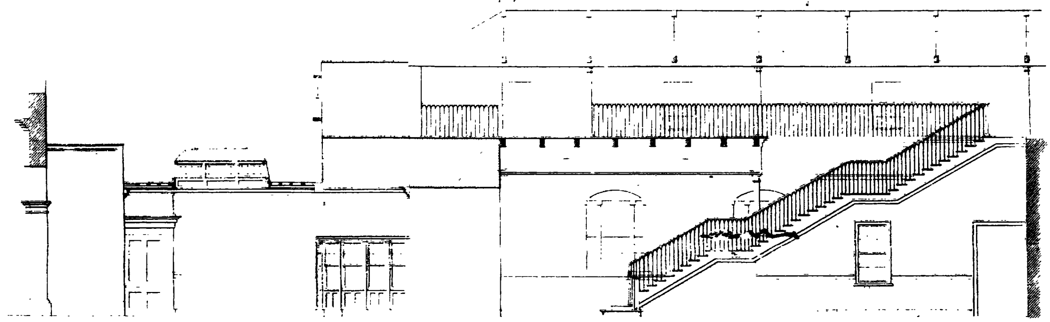
TERMINAL STATION.

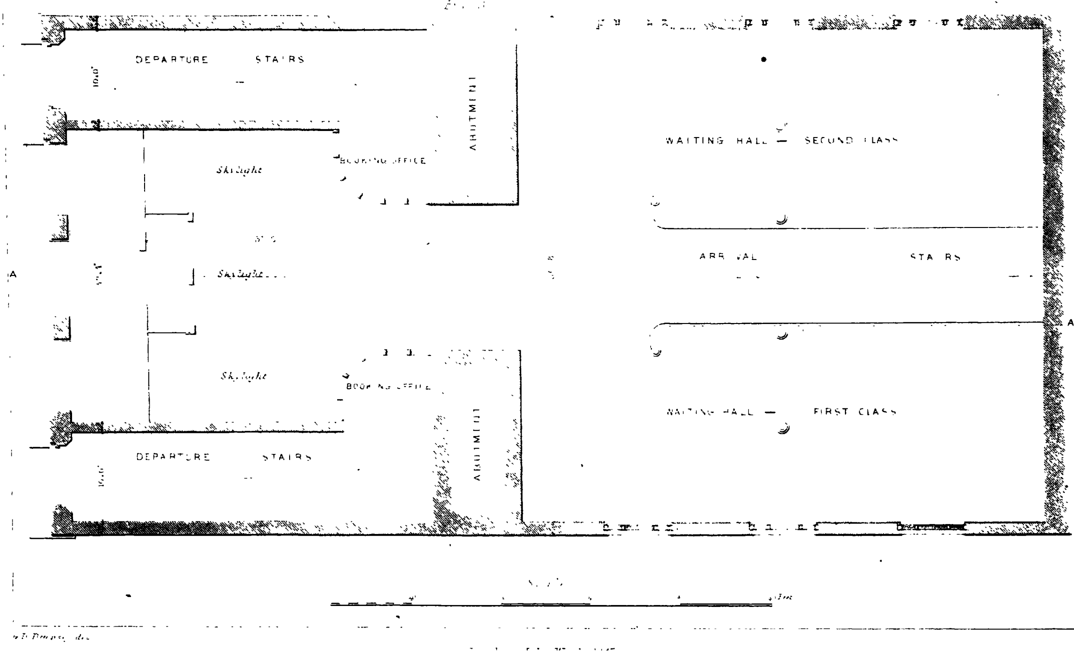


TERMINAL STATION

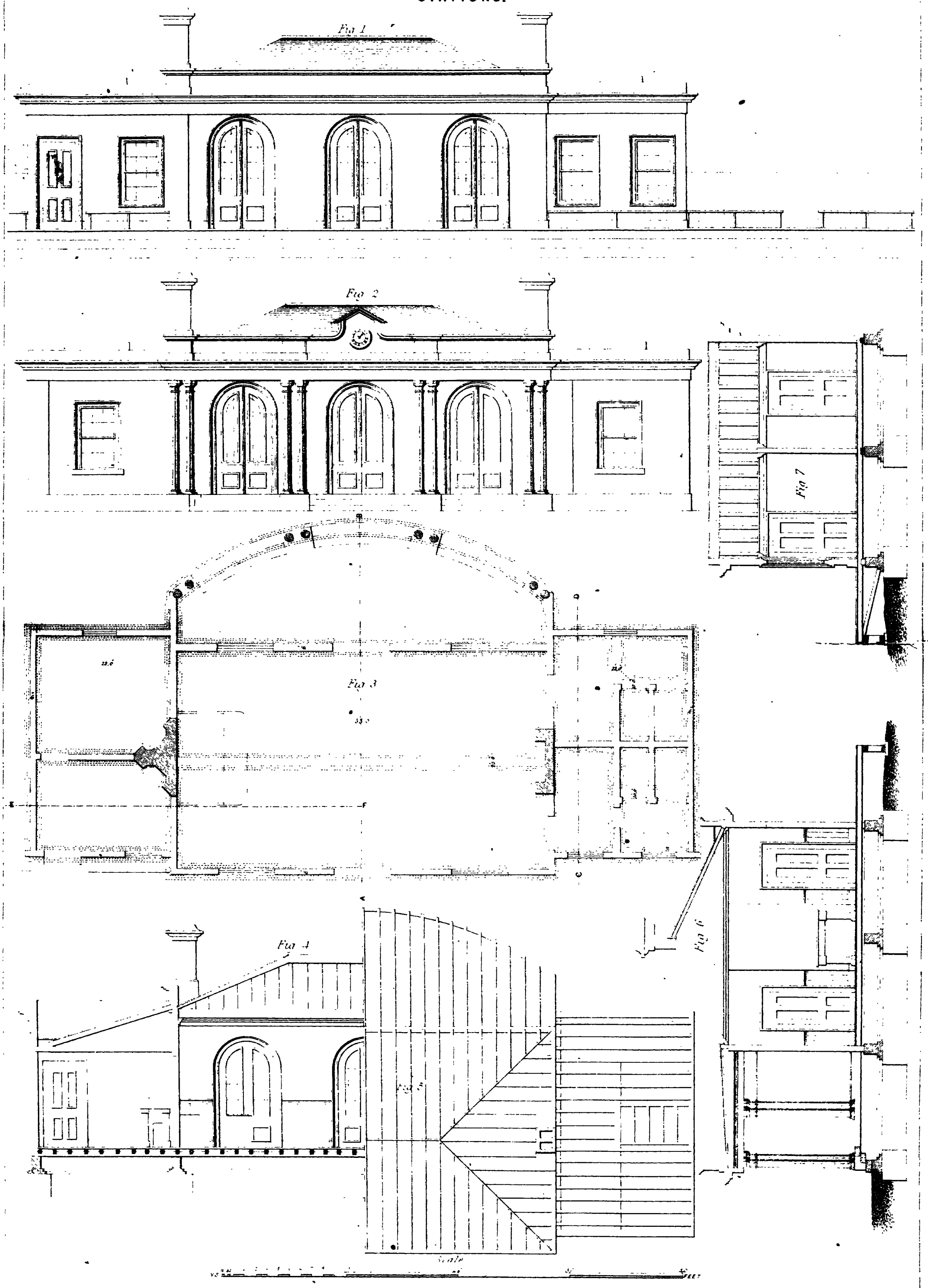






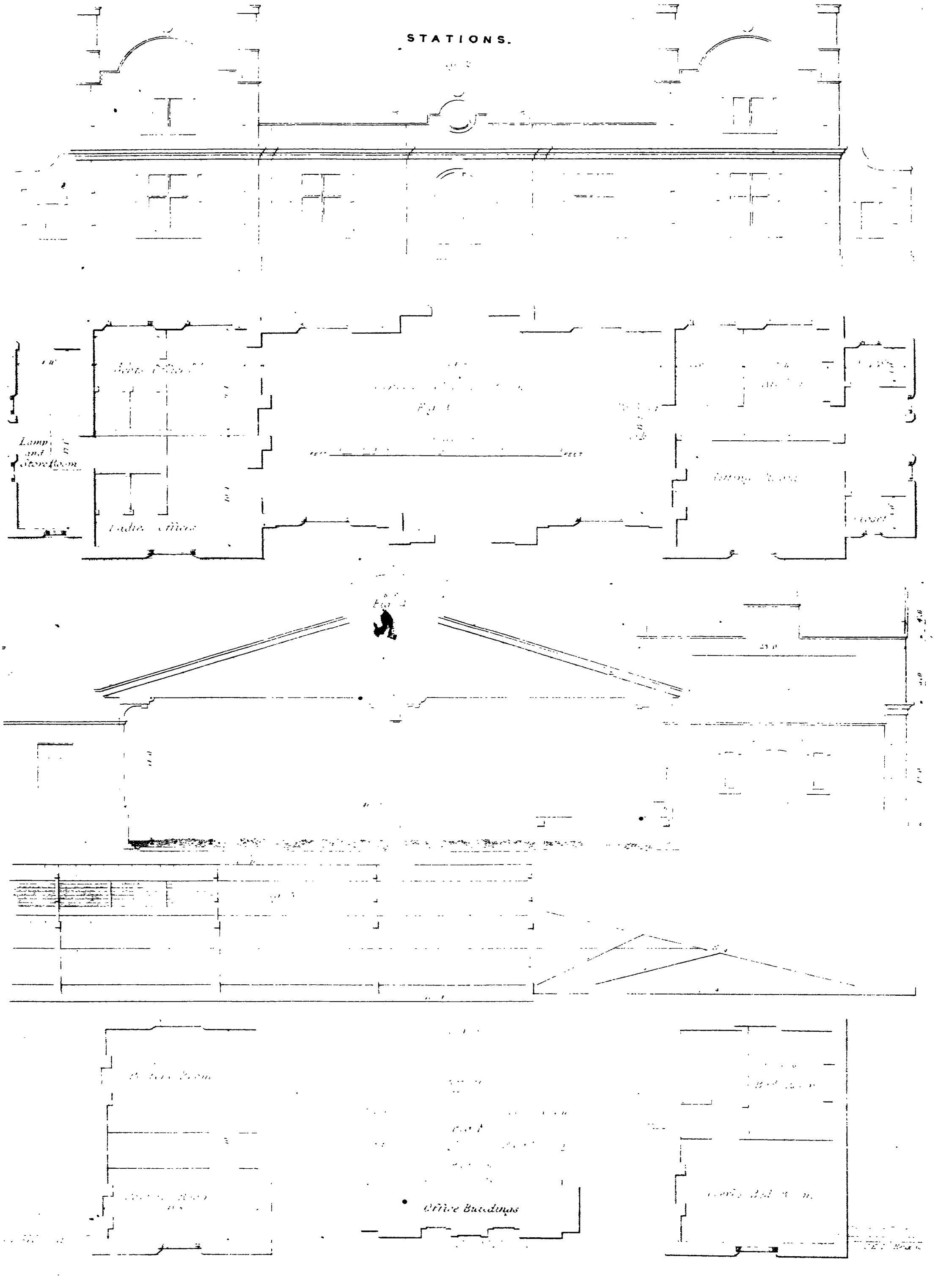


STATIONS.

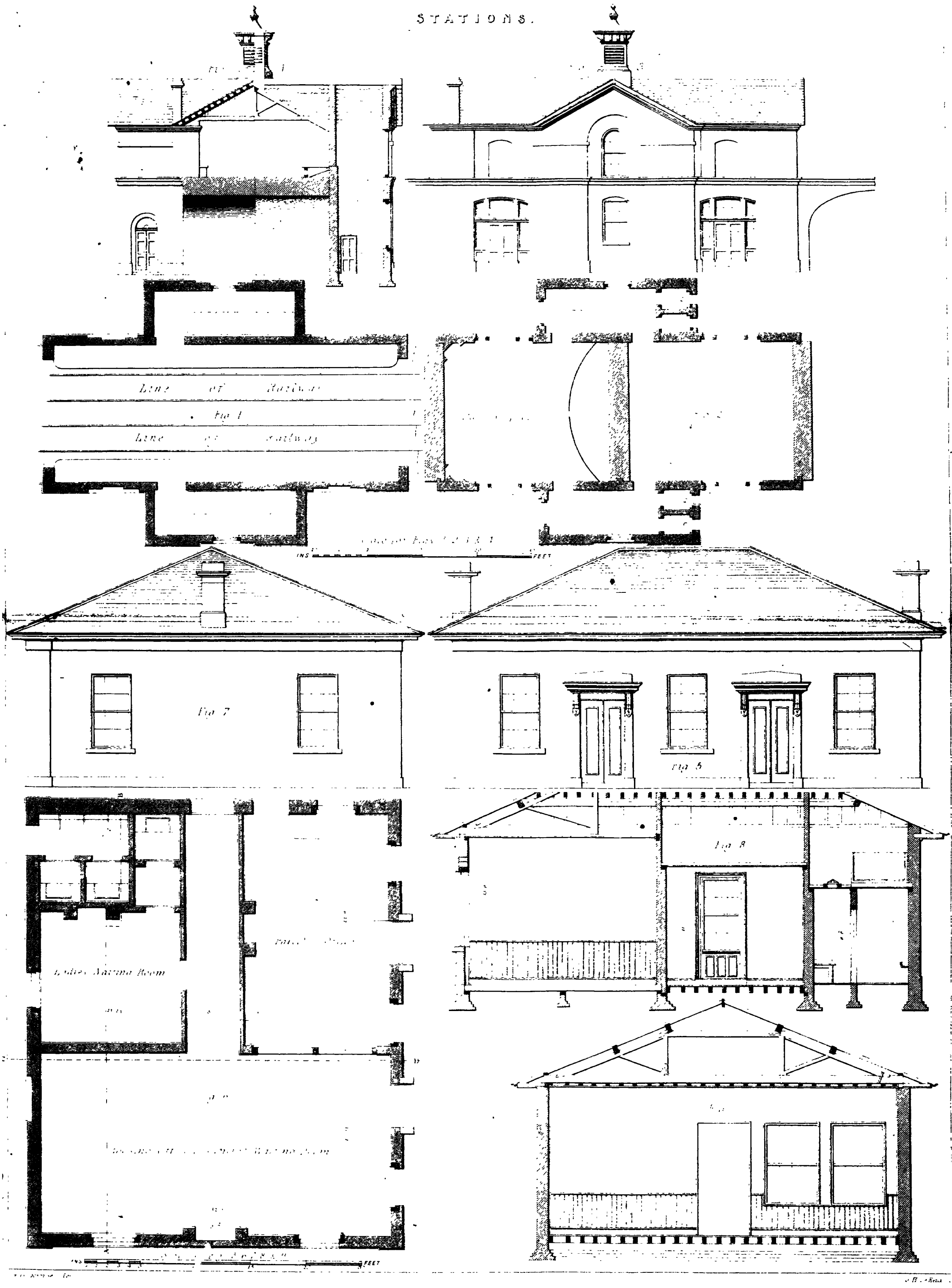


J.H. Le Keux sc

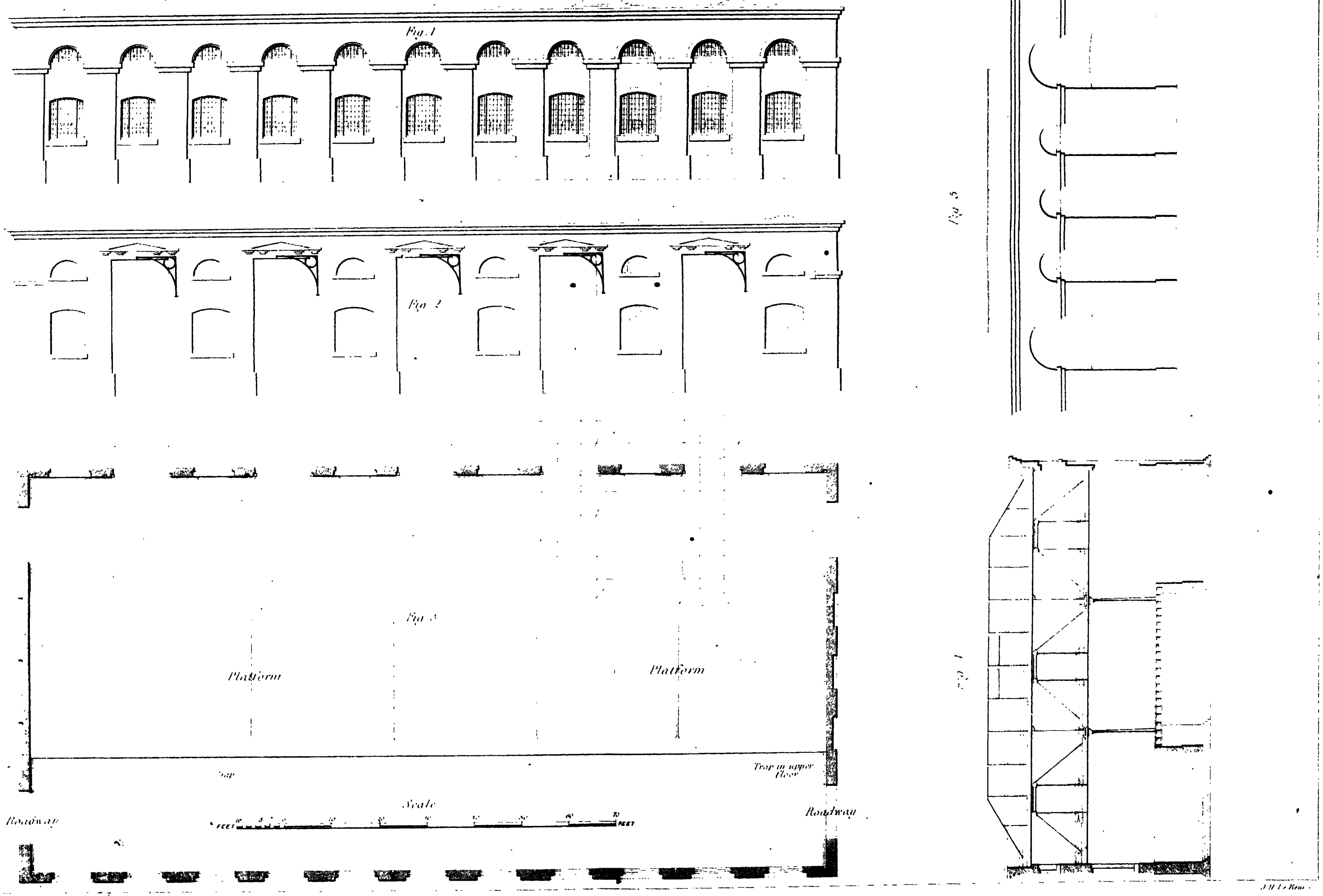
STATIONS.



STATIONS.


Line of Railway
Fig 1
Line of Railway
INS
FEET
Fig 7
Fig 5
Fig 8
Ladies Waiting Room
INS
FEET

GOODS STATION. A.



ENGINE HOUSE.

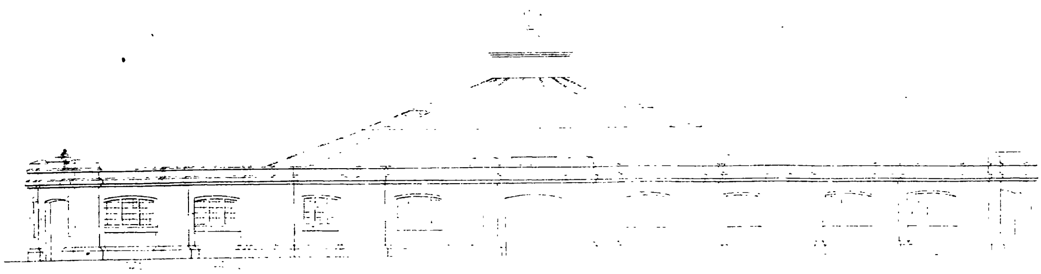
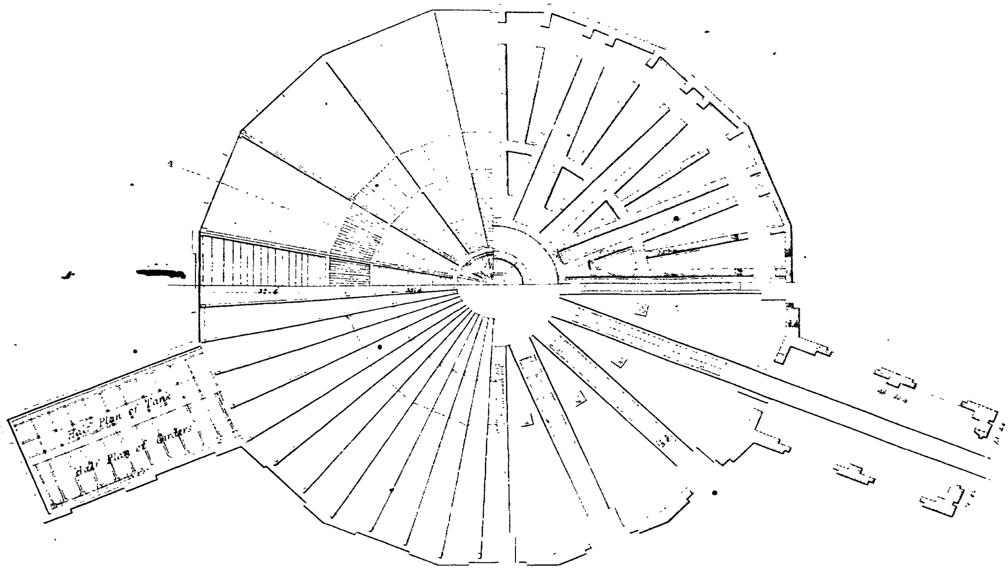
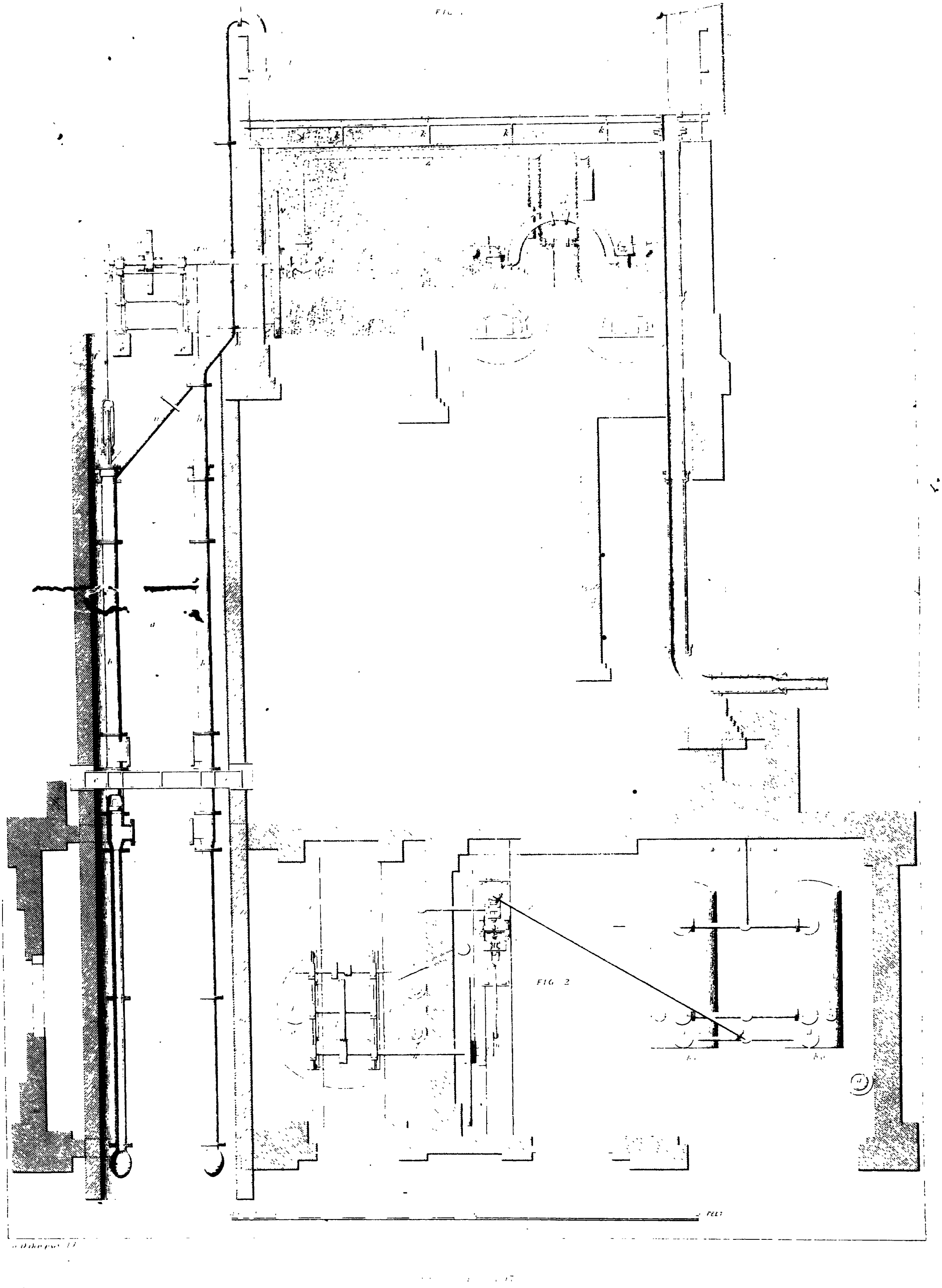


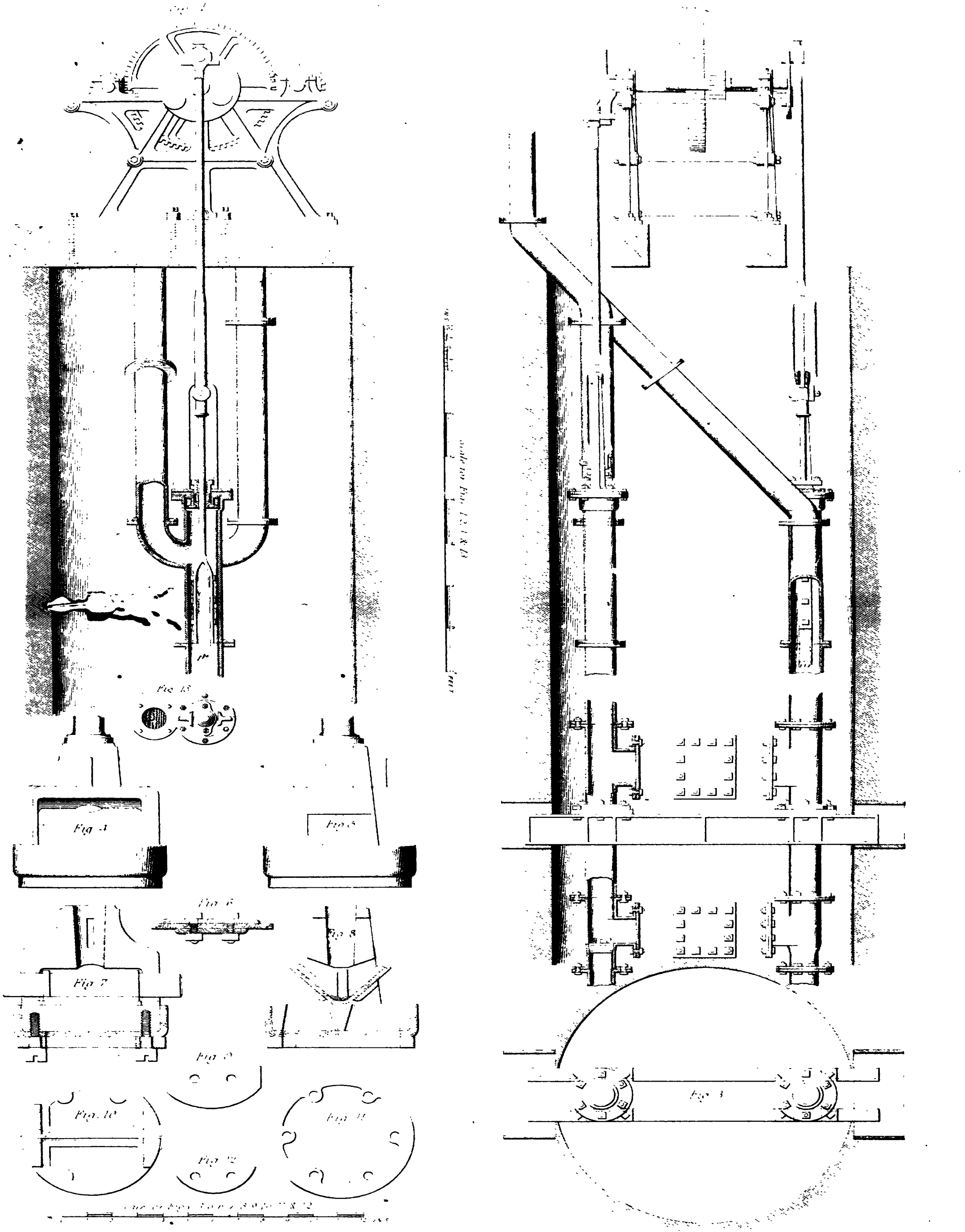
Fig. 2



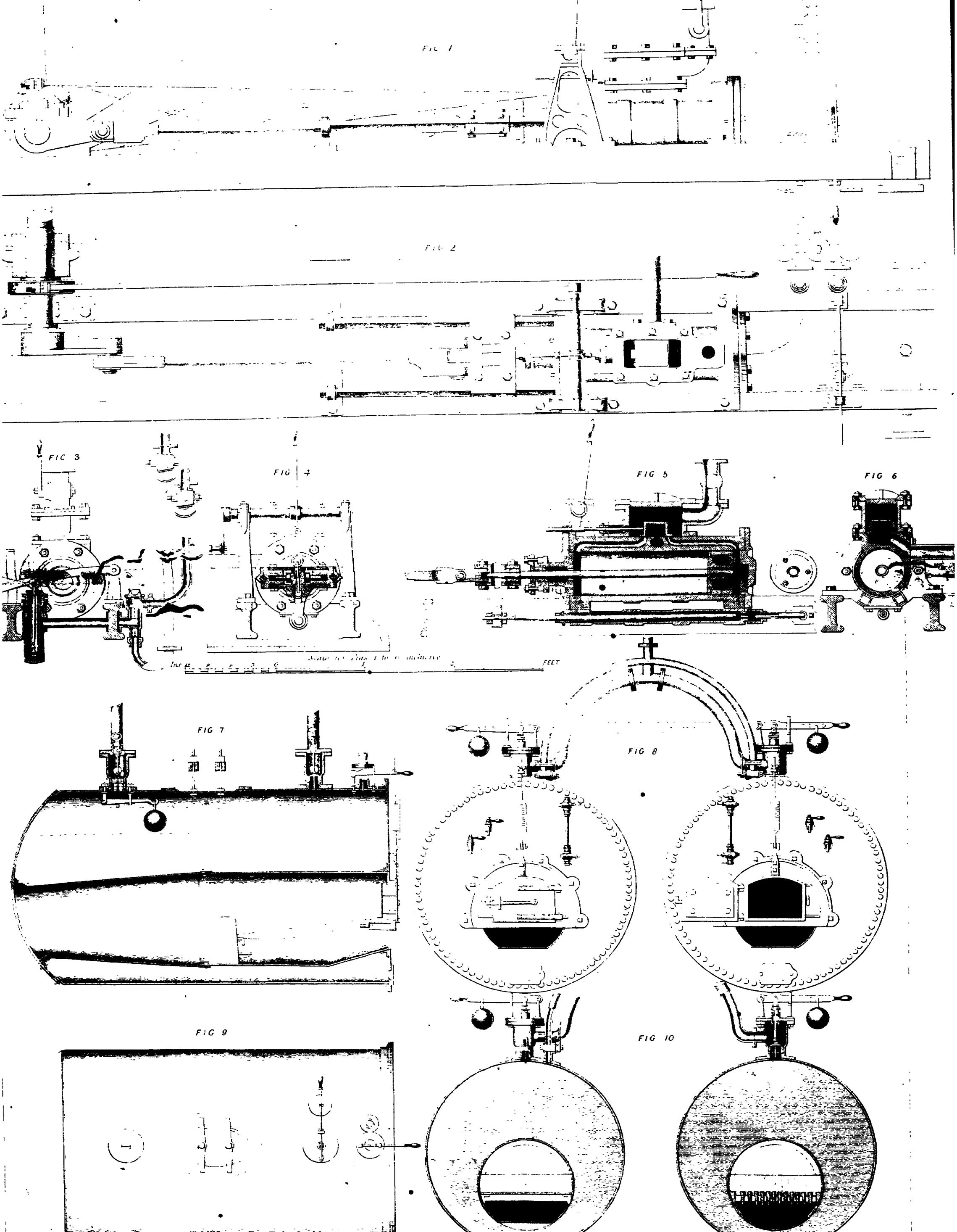
WATERING APPARATUS A



WATERING APPARATUS B.



WATERING APPARATUS C



D. Dempsey

London, John Weale 1847

WATERING APPARATUS. D.

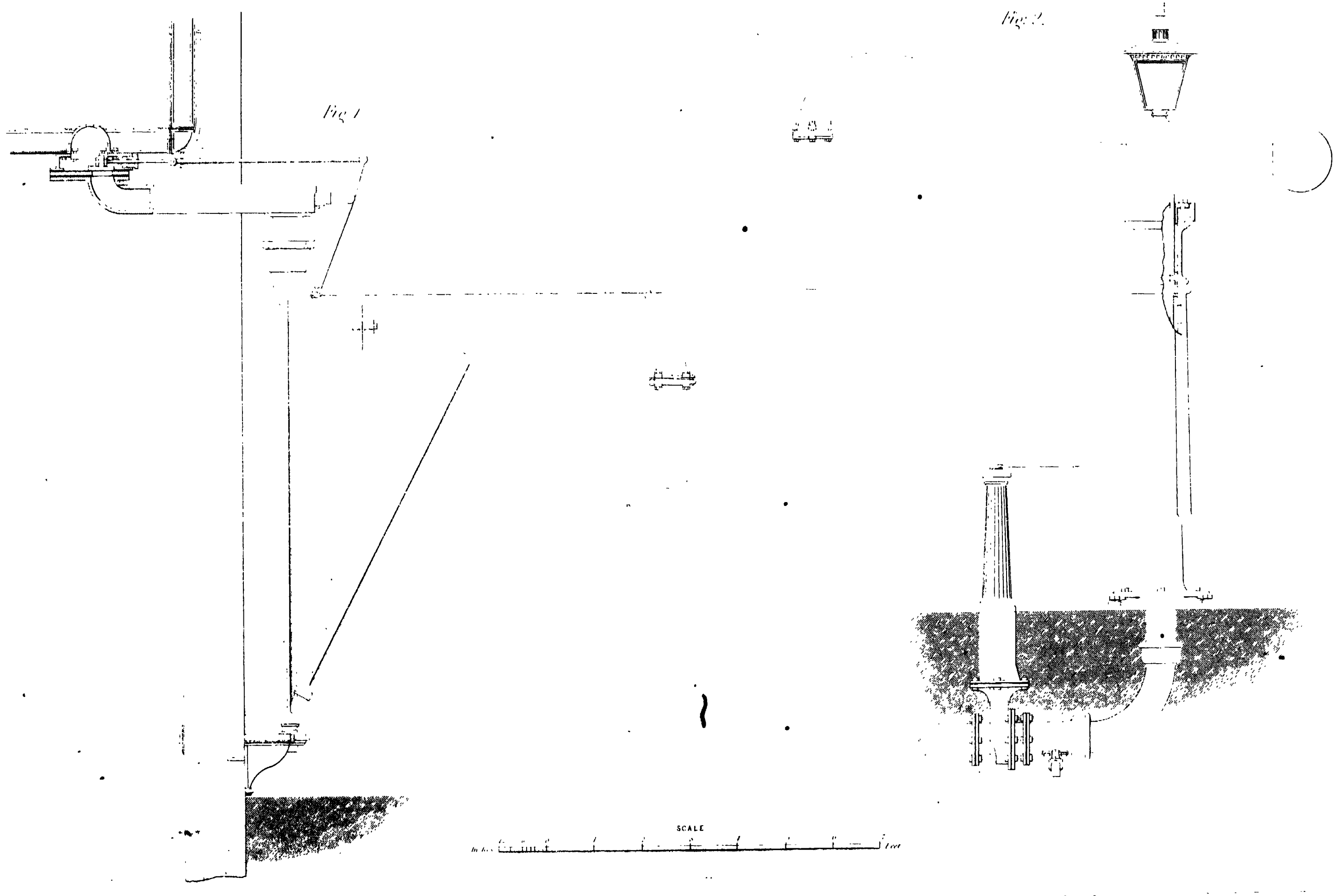


Fig 1

Fig 2

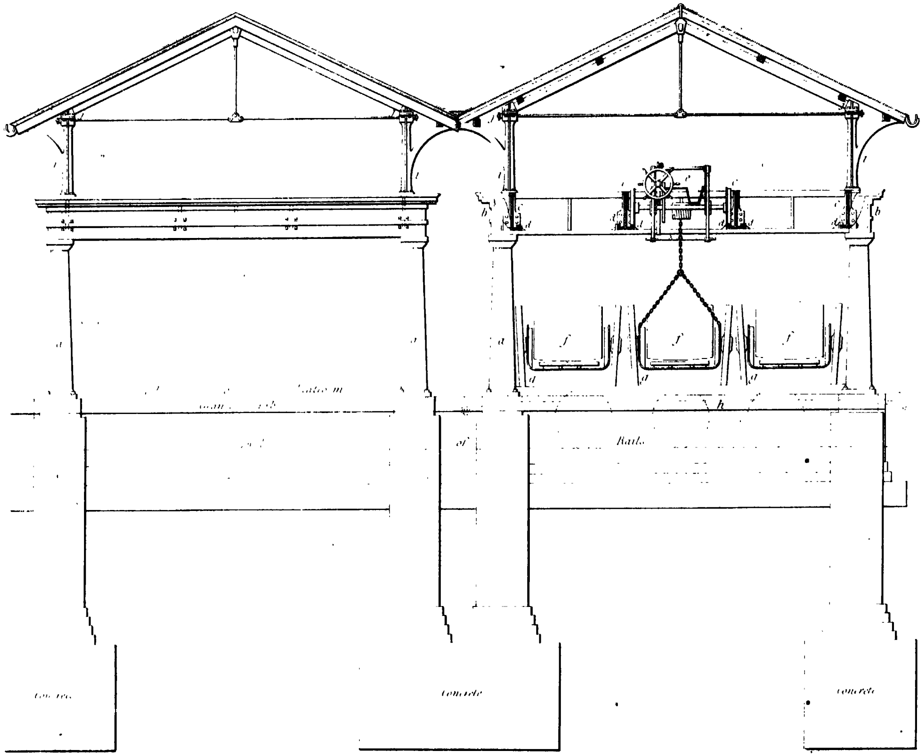
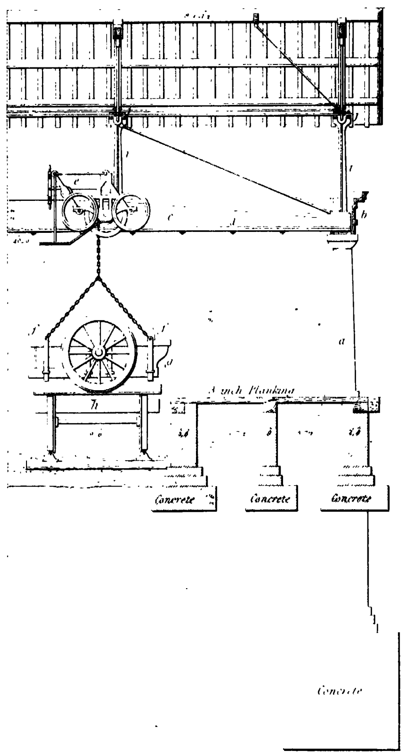
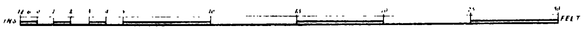


Fig 3



Scale



London John Weale

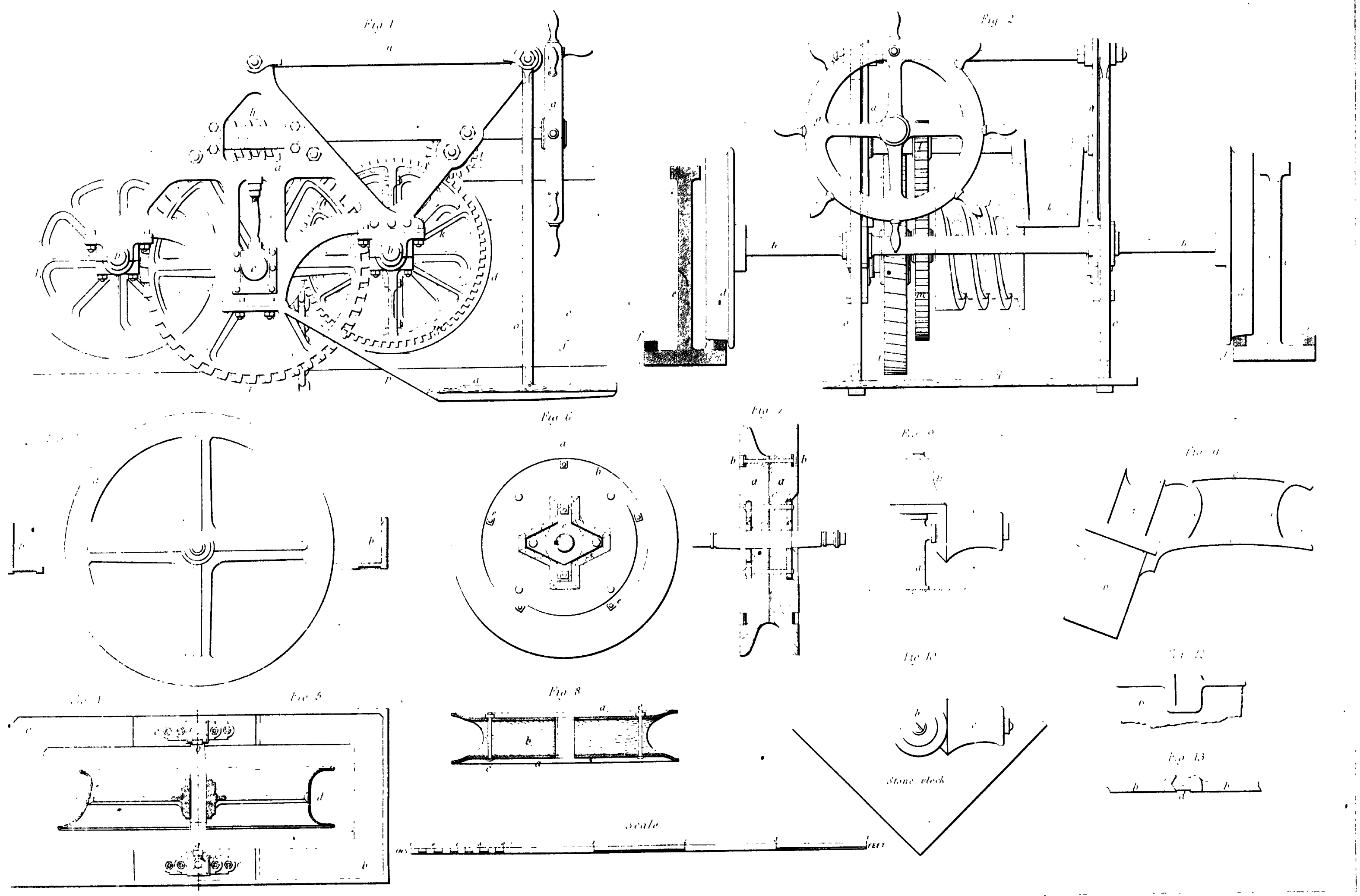


Fig 1
Fig 2
Fig 6
Fig 7
Fig 8
Fig 10
Fig 12
Fig 13
Fig 5
Stone block
scale
FEET

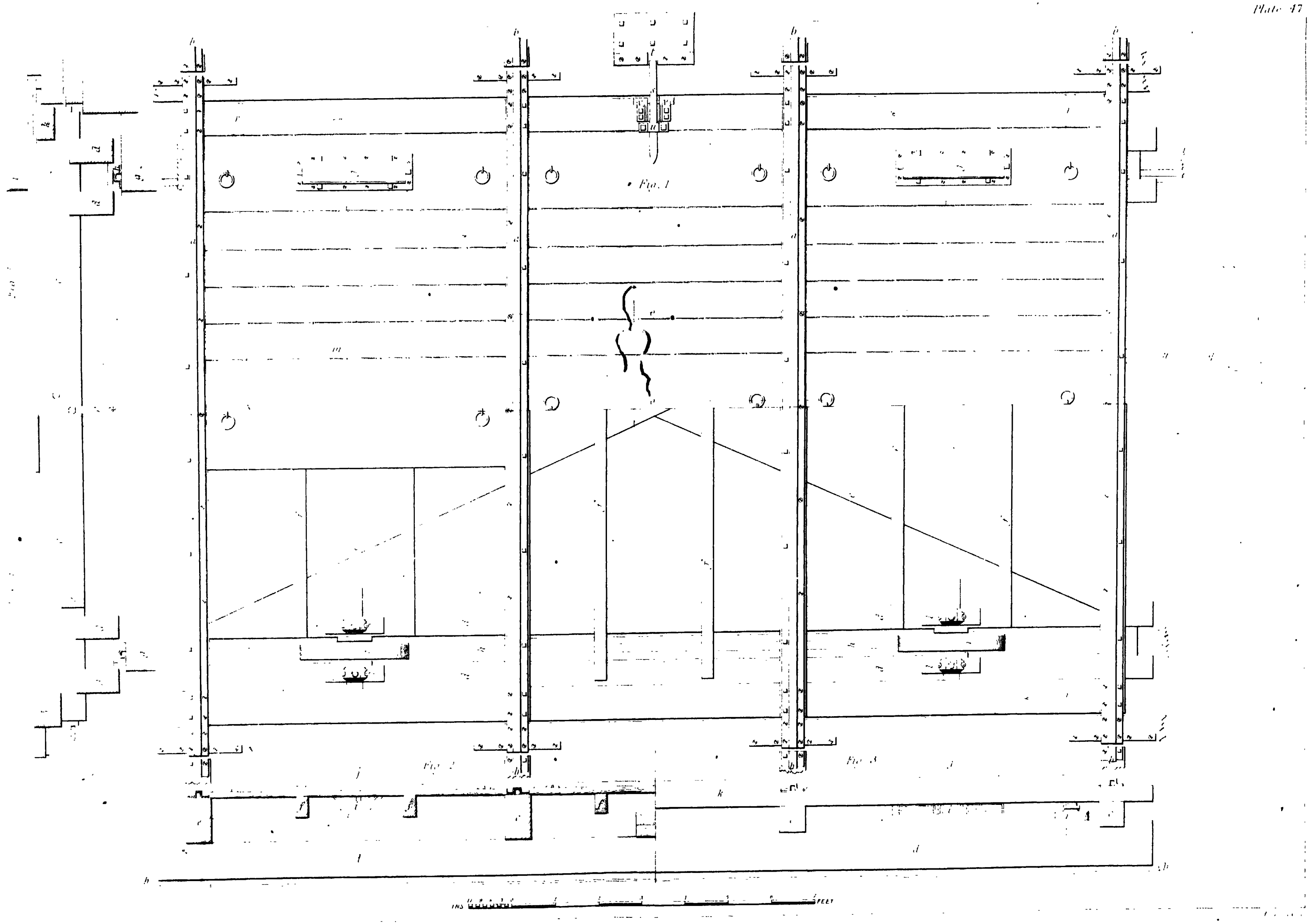


Fig. 1
Fig. 2
Fig. 3
INS
FEET

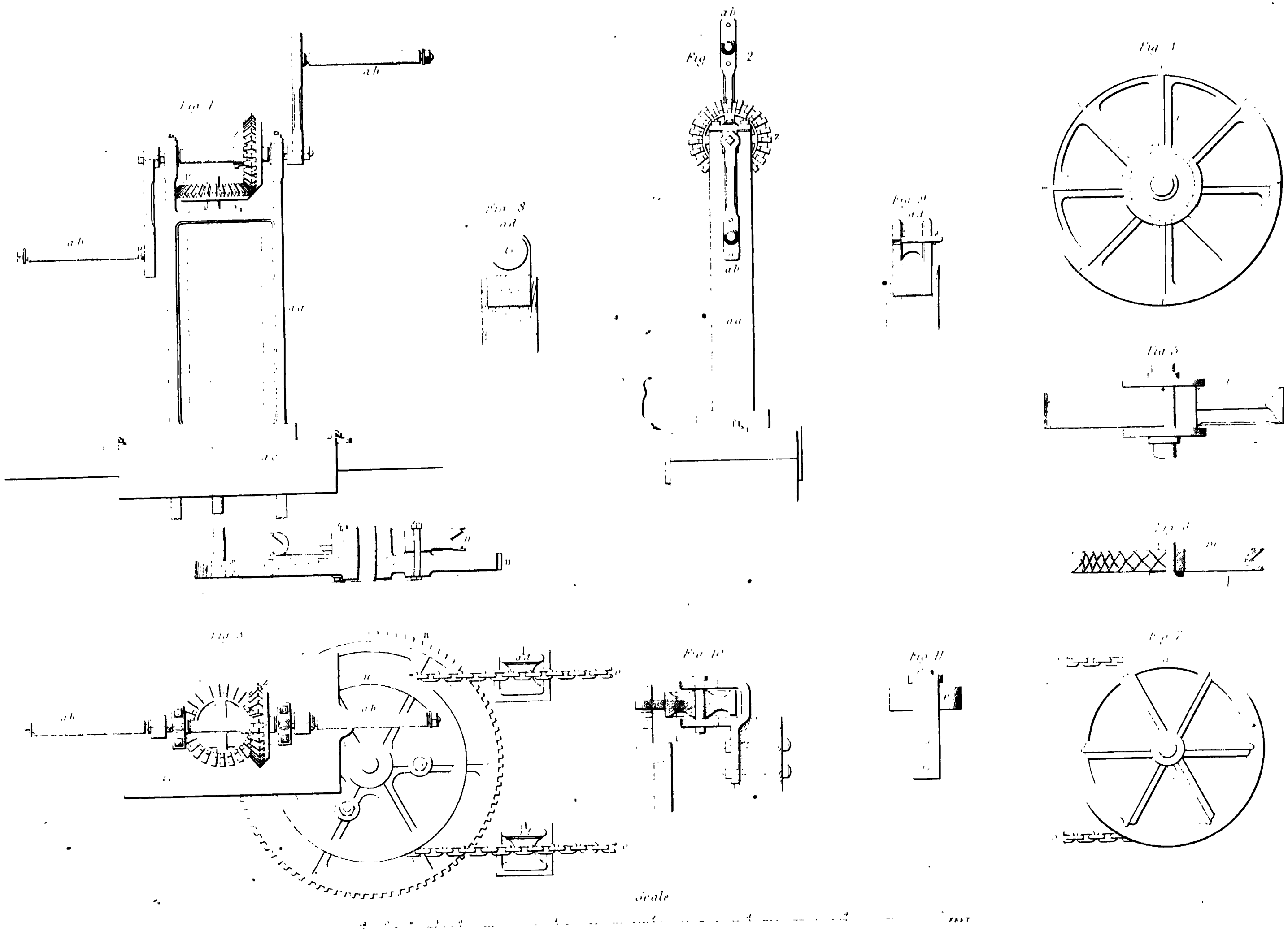


Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Fig 11
Scale
FEET

Plate 49.

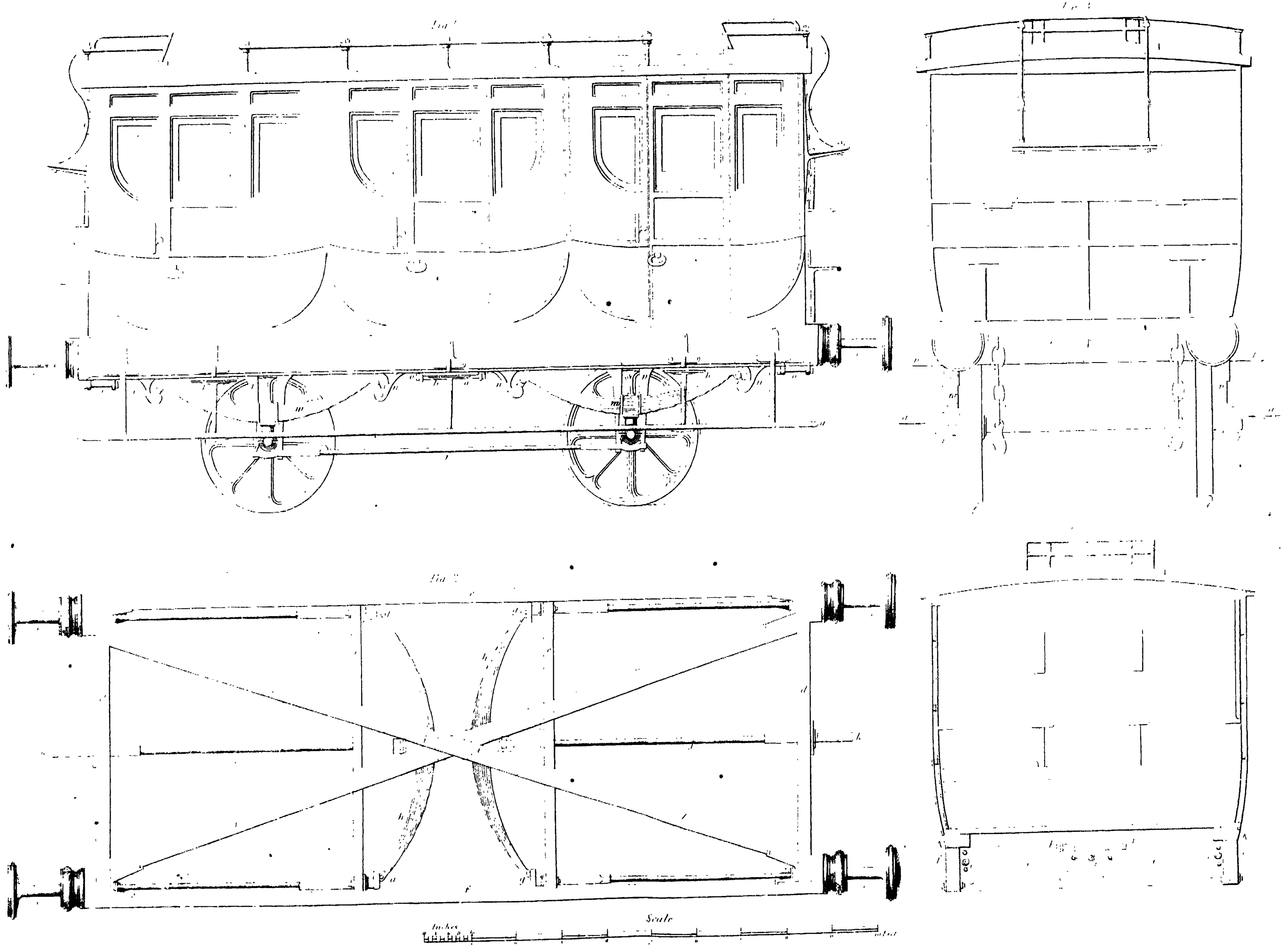


Plate 50

Fig 1

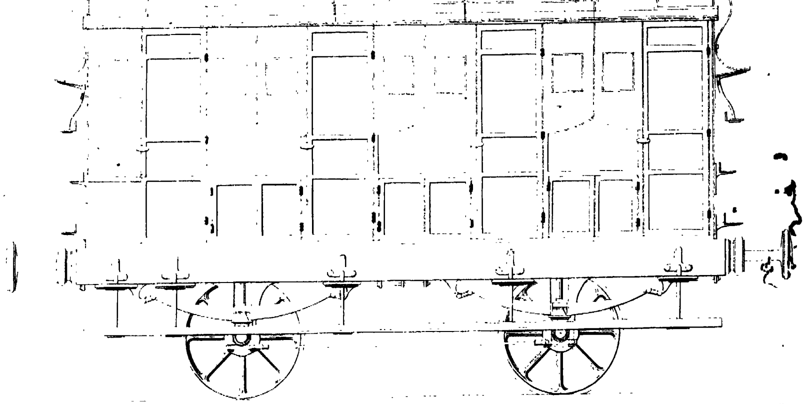


Fig 3

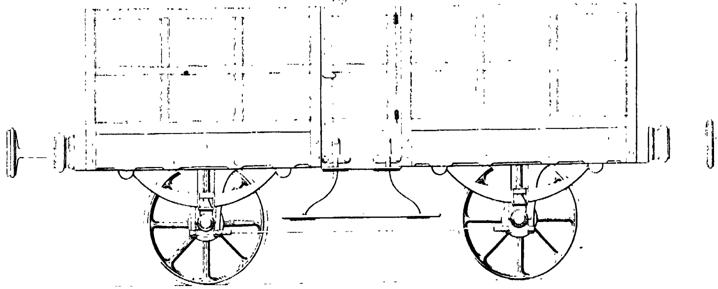


Fig 2

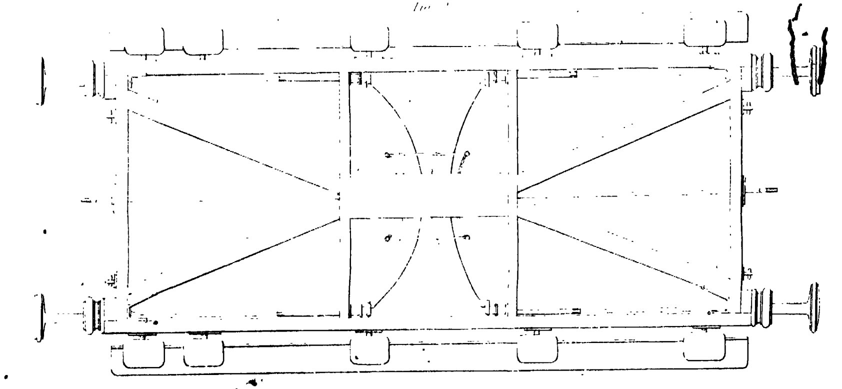


Fig 4

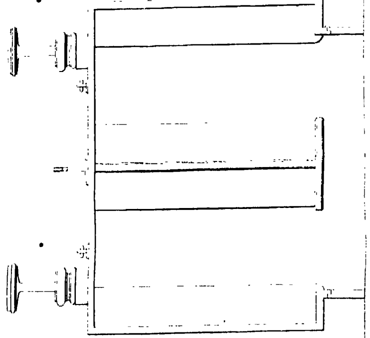
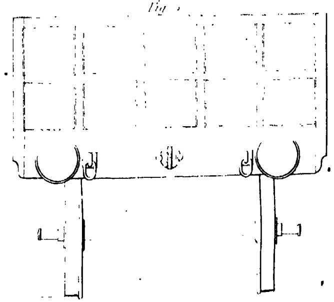


Fig 5



Ins Scale Feet

Plate 51

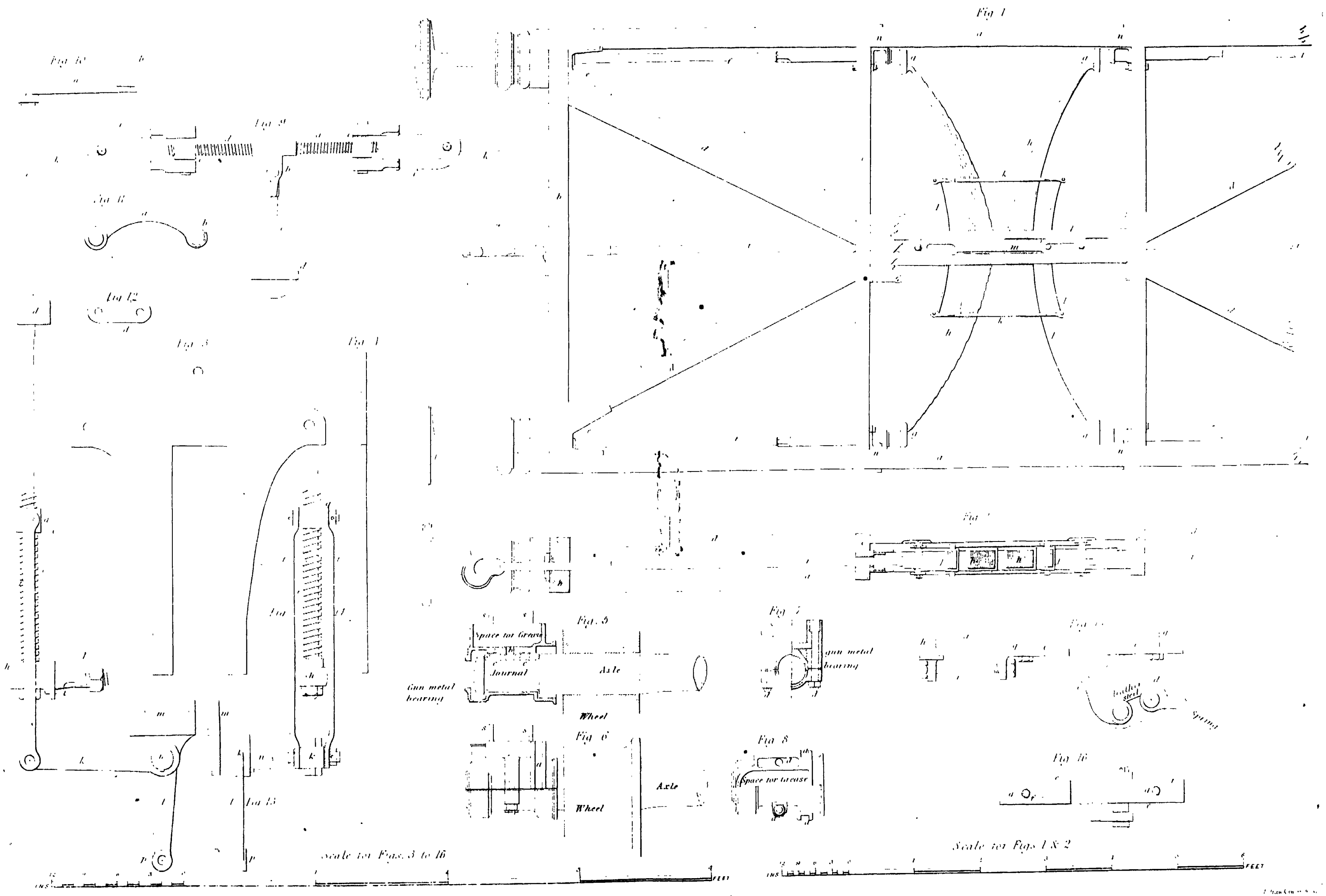


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 11
Fig. 12
Fig. 13
Fig. 16
Space for Grease
Journal
Axle
Gun metal bearing
Wheel
gun metal bearing
Space for grease
leather
steel
Spring
Scale for Figs. 3 to 16
Scale for Figs. 1 & 2
INS
FEET

Fig 1

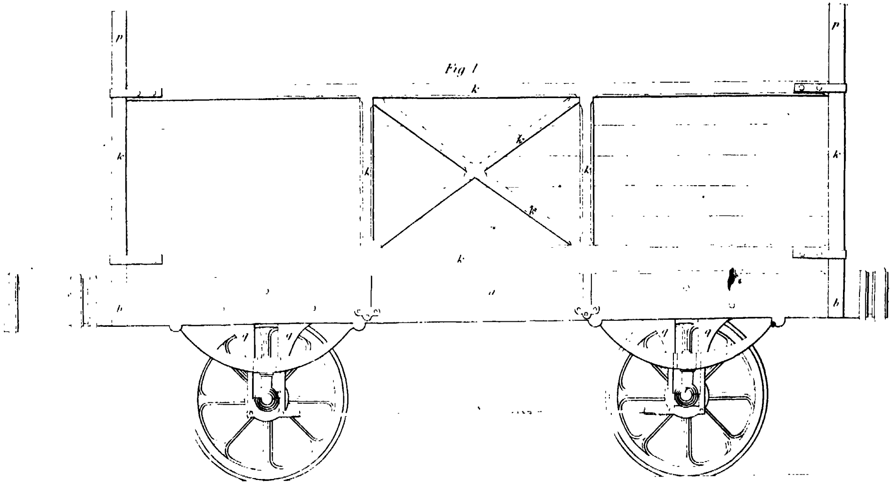


Fig 3.

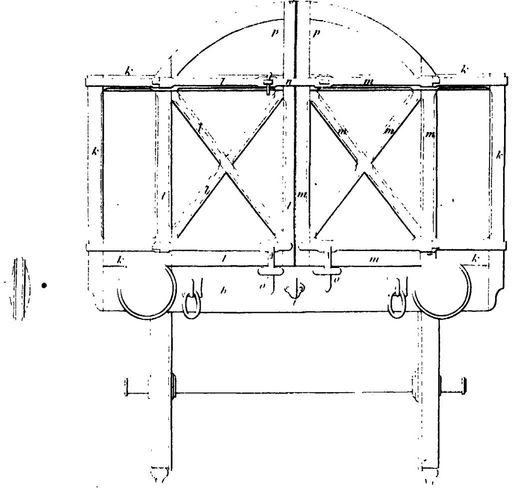
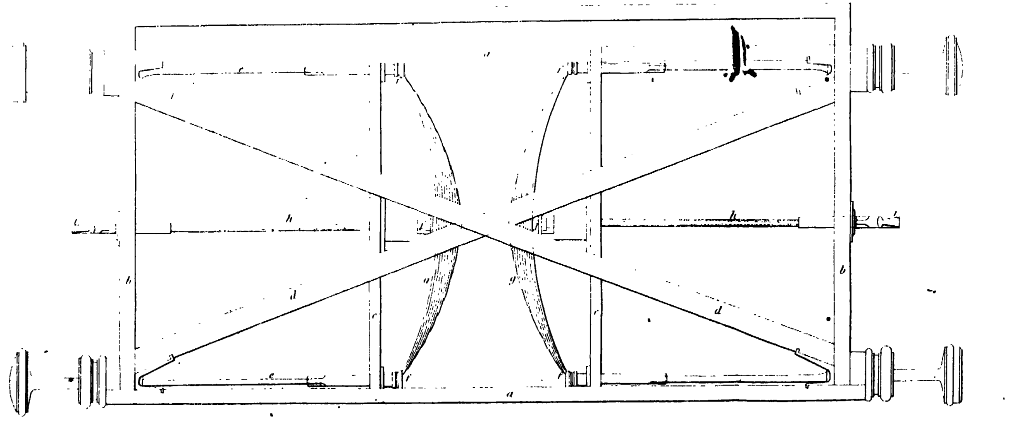
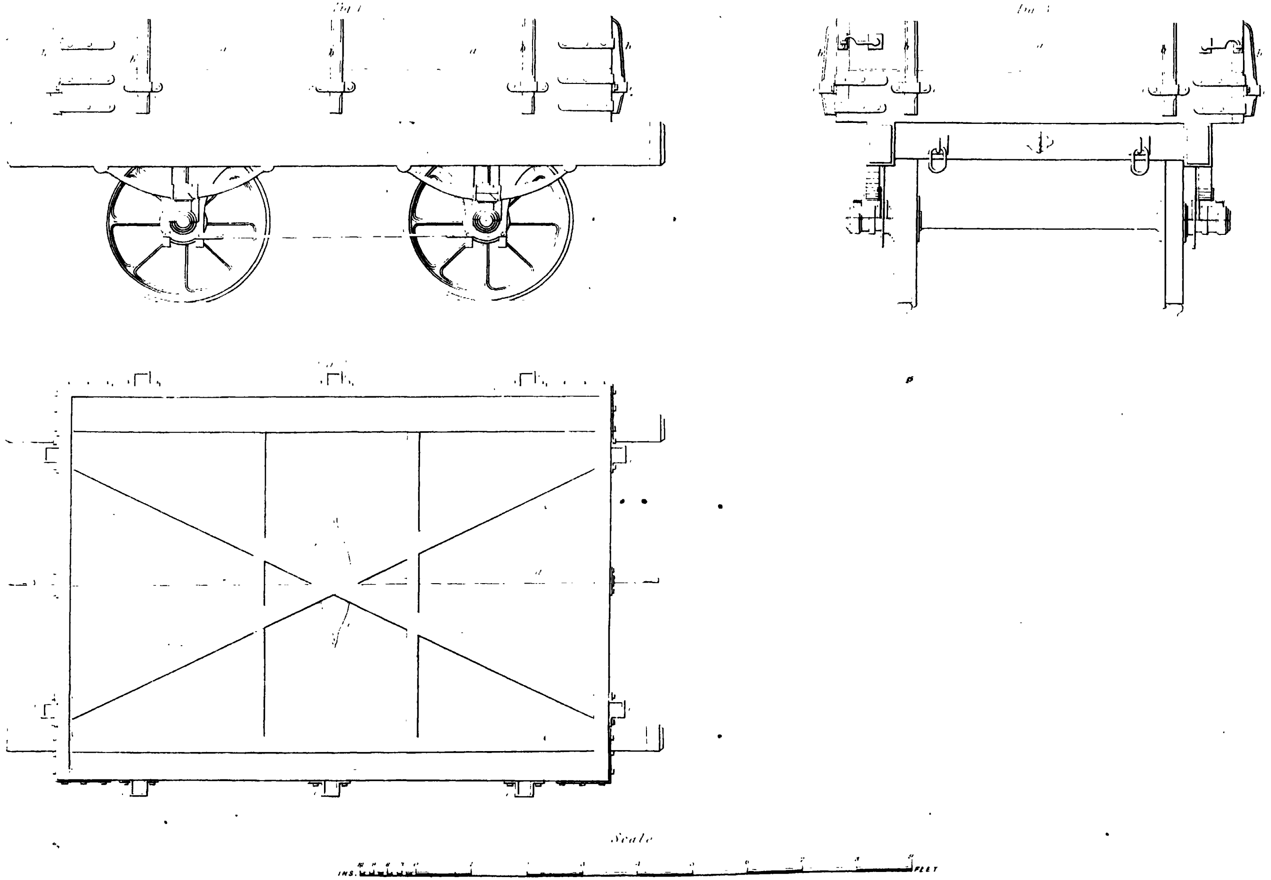


Fig 2



Scale

... del
... Hawksworth ...


Scale
INS.
FEET

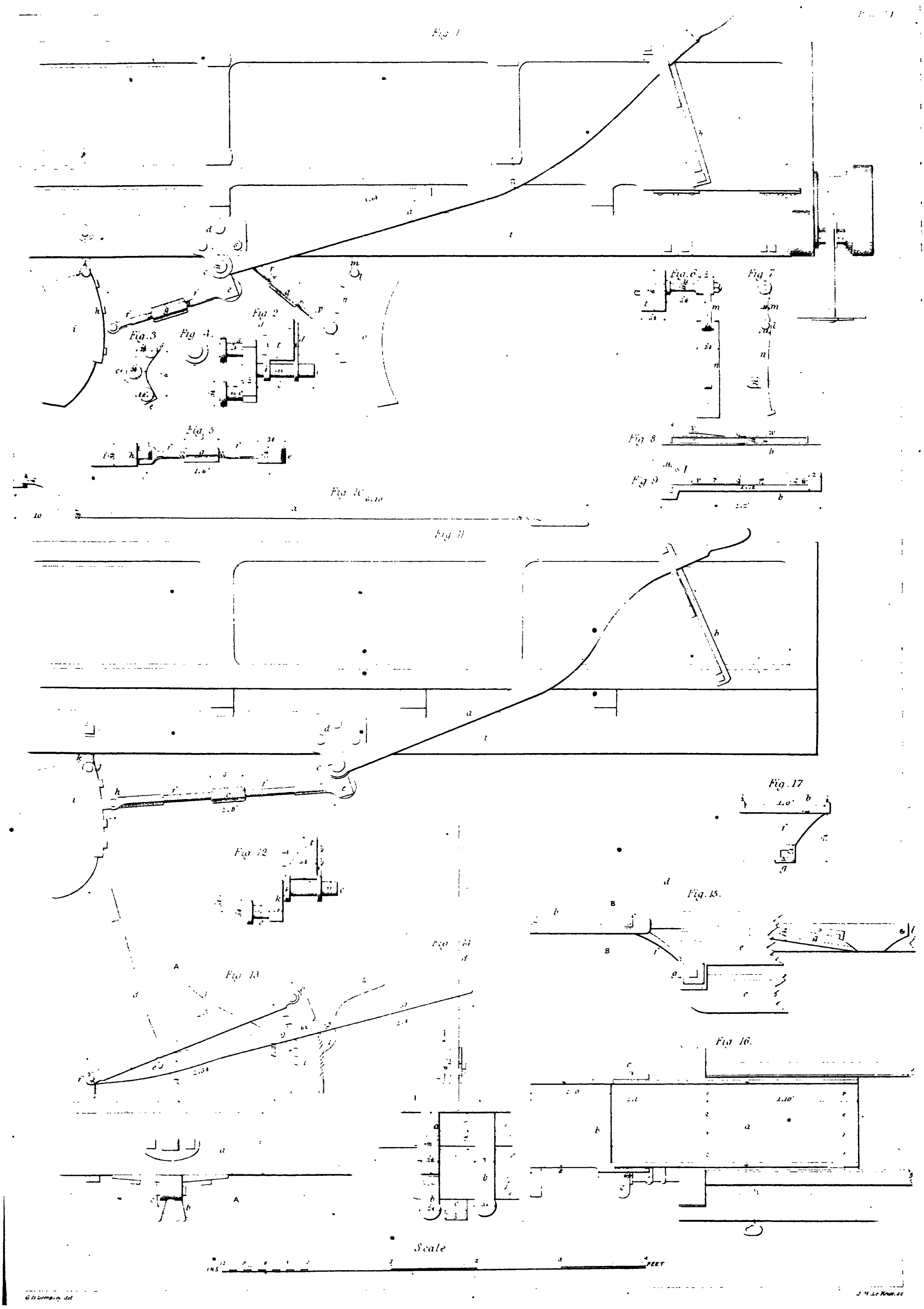


Fig. 1
Fig. 2
Fig. 3
Fig. 4.
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10
Fig. 11
Fig. 12
Fig. 13
Fig. 14
Fig. 15.
Fig. 16.
Fig. 17
Scale
INS
FEET

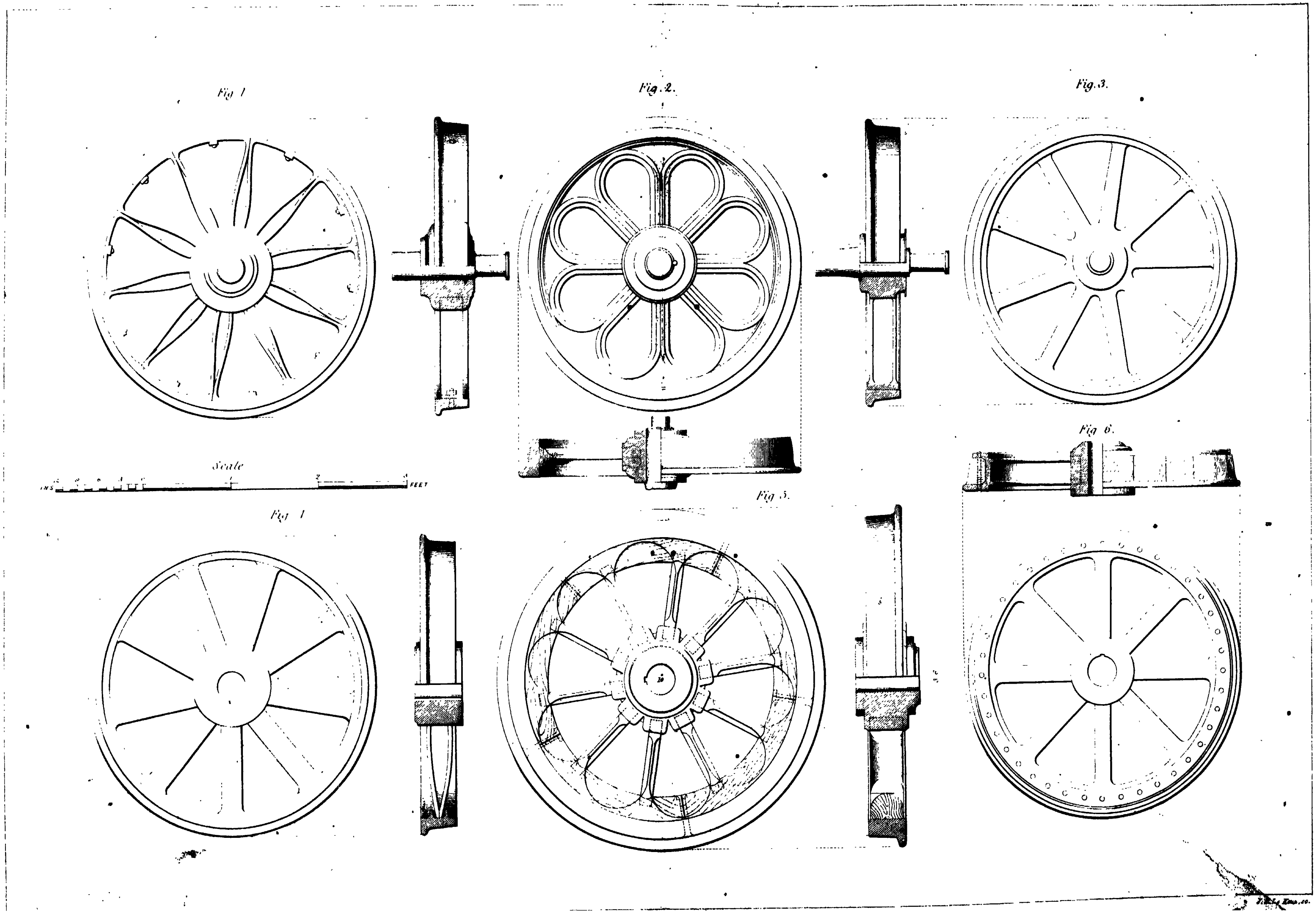


Fig 1
Fig. 2.
Fig. 3.
Scale
INS
FEET
Fig 6.
Fig 5.